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## Mild preexercise hyperhydration with electrolyte-containing beverages: effect on thirst, water intake, and physiologic function

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*Iowa State University*

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**Mild preexercise hyperhydration with electrolyte-containing beverages:  
effect on thirst, water intake, and physiologic function**

by

**Neil Michael Johannsen**

A dissertation submitted to the graduate faculty  
in partial fulfillment of the requirements for the degree of  
DOCTOR OF PHILOSOPHY

Major: Health and Human Performance (Biological Basis of Physical Activity)

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Ames, Iowa

2007

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## CHAPTER 1. INTRODUCTION

Physical activity produces metabolic heat that must be dissipated through a combination of conduction, convection, radiation, and evaporation. The proportions of these heat dissipating mechanisms depend on the environmental conditions, metabolic rate, and type and amount of clothing worn by the individual. During exercise, heat dissipation through evaporation must be maintained to prevent significant elevations in body temperature and possibly heat illnesses. Inadequate sweat rate and skin blood flow during exercise, especially in warm environments, exacerbates normal body temperature responses leading to decrements in performance and possibly health (1-5). Adequate water intake during exercise prevents this fall in sweat rate, resulting in effective core temperature maintenance and cardiovascular function. In contrast, inappropriate fluid replacement can cause more severe health problems such as coma or death associated with hyponatremia ( $[\text{Na}^+] < 135\text{mM}$ ; 6).

In 1996, the American College of Sports Medicine (ACSM) published a position stand on appropriate fluid replacement for exercise (7). The position stand states that individuals should drink 500 ml of fluid 2 hours before exercise or competition and continue to drink cool, flavored solutions containing carbohydrates (4 – 8 %) and sodium (0.5 – 0.7 g/l) at regular intervals during exercise in an attempt to replace all fluid lost in sweat (600 – 1200 ml/h). The recommendations for fluid replacement during exercise are an attempt to replace the losses associated with sweating (water and electrolytes) and glycolytic metabolism. However, the recommendations for preexercise fluid ingestion are for the most part unsubstantiated.

Sawka et al. (8) reevaluated the 1996 ACSM guidelines on fluid replacement for exercise and concluded that, because individual variability in running speed, sweat rate, and body size is high, people must customize their fluid intake. They recommend starting with 0.4 to 0.8 l/h of fluid containing sodium (0.5 – 0.7 g/l), potassium (0.08 – 0.2 g/l), and carbohydrate (5 – 10%) and drinking in order to keep body water losses < 2% in order to prevent potential detrimental effects on performance. These guidelines for fluid replacement are very similar to the previous report (7). However, preexercise fluid intake guidelines changed dramatically and emphasize euhydration (normal body water content) rather than overhydration. The preexercise guidelines state that hydration should start with 3 – 5 ml/kg body mass (210 – 350 ml for a 70 kg person) at least 4 hours before exercise and, if the urine is still concentrated, a similar bolus of fluid should be ingested 2 hours before exercise. The authors also state that the inclusion of sodium in a preexercise meal may prevent losses of water in the urine prior to the onset of exercise (9,10). In direct contrast to the initial position stand, hyperhydration with water or combination of water or glycerol is contraindicated because of a potential risk of excessive urination or dilutional hyponatremia.

Although the authors recommend this preexercise hyperhydration protocol, they also point out that the recommendations are based on inconsistent or limited experimental research (category B on their Strength of Recommendation Taxonomy; 8). Therefore, the primary purpose of this dissertation is to determine the degree to which preexercise beverage composition influences hydration during exercise. As stated in the position stand, preexercise meals may help stimulate thirst and retain beverages consumed during exercise. Another objective of this dissertation is to determine what components of preexercise



beverages maximize these effects during exercise and what internal mechanisms they exploit. The final aim is to determine whether the improved fluid balance associated with optimal preexercise hyperhydration beverages provides significant improvements in cardiovascular function, temperature regulation, and physical and cognitive performance during exercise in the heat.

### **Dissertation Organization**

After the introduction and review of literature, three manuscripts will be presented. The first manuscript will address the effect of preexercise beverage composition on fluid balance and physical performance during exercise in a thermoneutral environment. The second manuscript utilizes a resting protocol in an attempt to delineate effects of beverage composition on physiologic changes observed in the first study. The culminating manuscript investigates the effect of beverage composition on fluid balance, physiologic function, and performance during exercise in a hot, dry climate.

- Chapter 3.     Johannsen, N. M., E. Lind, D. S. King, and R. L. Sharp. Effect of preexercise beverage ingestion on fluid balance and exercise tolerance.
- Chapter 4.     Johannsen, N. M., F. Macaluso, M. C. Carlson, D. S. King, and R. L. Sharp. Effect of electrolyte-containing beverages on hydration.
- Chapter 5.     Johannsen, N. M., N. Warnke, D. S. King, and R. L. Sharp. Preexercise beverage composition impact on hydration and performance under compensable heat stress.

Chapter 6 provides general conclusions that can be drawn from this dissertation and includes future directions for research.

## CHAPTER 2. REVIEW OF LITERATURE

### Exercise and dehydration in the heat

Exercise in the heat has large effects on cardiovascular strain, the ability to regulate core body temperature, and performance because of an increase in the reliance on body fluid distribution to the skin to maintain adequate sweat rates and heat dissipation. Heat is dissipated via conduction, convection, evaporation, and radiation during exercise. During exercise in the heat, the overall contribution of conduction, convection, and radiation to heat losses decreases dramatically, leaving the burden of heat loss to evaporation. The condition in which required heat losses ( $E_{req}$ ) by evaporation are less than the capacity of the environment for heat loss ( $E_{max}$ ) is termed compensable heat stress (11). Uncompensable heat stress, on the other hand, occurs when, even at maximal sweat rate, heat dissipation is inadequate ( $E_{max} < E_{req}$ ). Under uncompensable heat stress conditions, fluid balance is less important due to ineffective evaporative heat losses and rapid elevations in core body temperature associated with fatigue (12). However, because of the additional burden placed on sweat for heat dissipation during exercise under compensable heat stress, dehydration has severe consequences for cardiovascular function, temperature regulation, and performance.

Previous research has shown that dehydration during exercise has detrimental effects on sweat rate and skin blood flow. Specifically, Montain et al. (1) demonstrated that elevated levels of dehydration corresponded to greater decreases in stroke volume and skin blood flow and concomitantly higher core body temperatures and heart rates. However, even though participants in the study lost approximately 4% of their body mass in a no fluid trial during 2 h of exercise in a warm environment, the absolute sweat rate was preserved. Other research

supports these data demonstrating a similar decline in temperature regulation with graded dehydration, but unlike Montain et al. (1), a reduction in sweat rate was observed (2). These data suggest that if fluid is given during exercise in order to counteract dehydration (1), sweat rate appears to be maintained, but if fluid is only given to maintain a given percent dehydration (2), sweat rates are compromised. When sweat rates are controlled for changes in core body temperature (sweat sensitivity), the studies results were identical. Further research indicates that the combination of dehydration and hyperthermia, as observed with water restriction during exercise, leads to exacerbated declines in cardiac output, mean arterial pressure, and stroke volume while increasing heart rate and systemic vascular resistance (14,13,14). Nadel et al. (4,5) also demonstrated that when heat strain and body fluid losses are great (-21% plasma volume change), skin blood flow and sweat rate is compromised to preserve cardiovascular function.

Further evidence of the importance of body fluids during exercise in the heat comes from heat acclimation studies. Armstrong and Maresh (15) demonstrated that heat acclimation reduces heart rate and rectal temperature and increases stroke volume due to increased plasma volume, sweat rate, and sweat sensitivity (change in sweat rate per degree body temperature increase). These adaptations are primarily caused by reduced urinary output due to a combination of increased plasma protein (16), and water regulating hormones (aldosterone, arginine vasopressin, renin; 15,16). While the adaptations in water regulating hormones seem to be transient, disappearing after approximately 12 days, the increase in plasma protein persists while in the acclimated state. The increase in water regulating hormones and plasma protein cause an increase in plasma volume by increasing the ability to

hold water (increase in plasma protein) and decreasing urine output. Increased plasma volume may allow for a higher stroke volume and absolute cardiac output to be diverted to the skin and to sweat. The main physiologic benefits of these adaptations are a reduction in cumulative heat storage attributable to greater evaporative heat losses and improved blood pressure control due to increased stroke volume, and therefore, cardiac output. An earlier sweat response decreases the amount of heat that accumulates at the start of exercise further decreasing metabolic heat production by the  $Q_{10}$  effect. These data suggest that normally individuals have inadequate water intake during exercise and that plasma volume expansion prior to exercise may result in physiologic benefits during exercise. Grant et al. (17) supports this idea demonstrating that plasma volume expansion (14-21%) by dextran infusion reduces cardiovascular (reduced heart rate and increased stroke volume) and thermal strain late in exercise. These results are similar to Hamilton et al. (18); however, Montain and Coyle (19) indicate that improved cardiovascular function and temperature regulation are magnified if blood volume expansion is the result of increased fluid intake and not forced intravenous volume expansion. Still other research indicates that, as long as the skin stays moist in exercise (20), adequate temperature regulation exists. The additional body fluids may only serve to preserve adequate cardiovascular function and extra sweat losses in exercise may be detrimental. Regardless of the cardiovascular adaptations, exhaustion in the heat seems to be dependent only on the ability to regulate core temperature as indicated by Gonzalez-Alonso et al. (21) and Nielsen et al. (16) where volitional fatigue occurred at a core body temperature of 39.7 to 40.2°C.

## Importance of water intake during exercise

Early research investigating *ad libitum* fluid ingestion during exercise indicates that most people replace only ~70% of total water loss (22,23). Assuming this to be true, the extent of dehydration depends on the rate of water lost due to evaporation (sweat and respiratory water losses), the amount of water lost in urine, and the duration of exercise. Obviously, if exercise duration is short and the individual starts the activity in a euhydrated state, significant dehydration is not plausible. However, individuals participating in exercise in excess of 2 h run the risk of dehydration and the negative outcomes associated with the loss of significant amounts of body water, especially if the event is conducted in the heat. For example, a 70 kg marathon runner will dehydrate ~0.7%/h, assuming fluid ingestion is 70% of total water loss and total evaporative losses are 1.4 L/h and urine losses are 300 ml/h. These data are well within the normal ranges and, as will be discussed later in this review, if the athlete takes 3 h to finish the marathon, significant physical and cognitive decrements may occur.

During exercise, the body must compromise to adequately supply the circulatory system with fluid to maintain cardiac output due to an increase in oxygen demand in the muscle while at the same time providing adequate fluid to the skin for the production of sweat to regulate body temperature. The rise in body temperature is directly related to heat storage and can be expressed by the following equation where HS is the rate of heat storage (J/s), M is total metabolic heat production (total caloric expenditure – physical work produced), and Cv, Cd, R, and E are rates of heat loss or gain by convection, conduction,

radiation, and evaporation, respectively. Heat storage can also be calculated indirectly by the change in mean body temperature (24).

$$HS = M \pm C_v \pm C_d \pm R - E$$

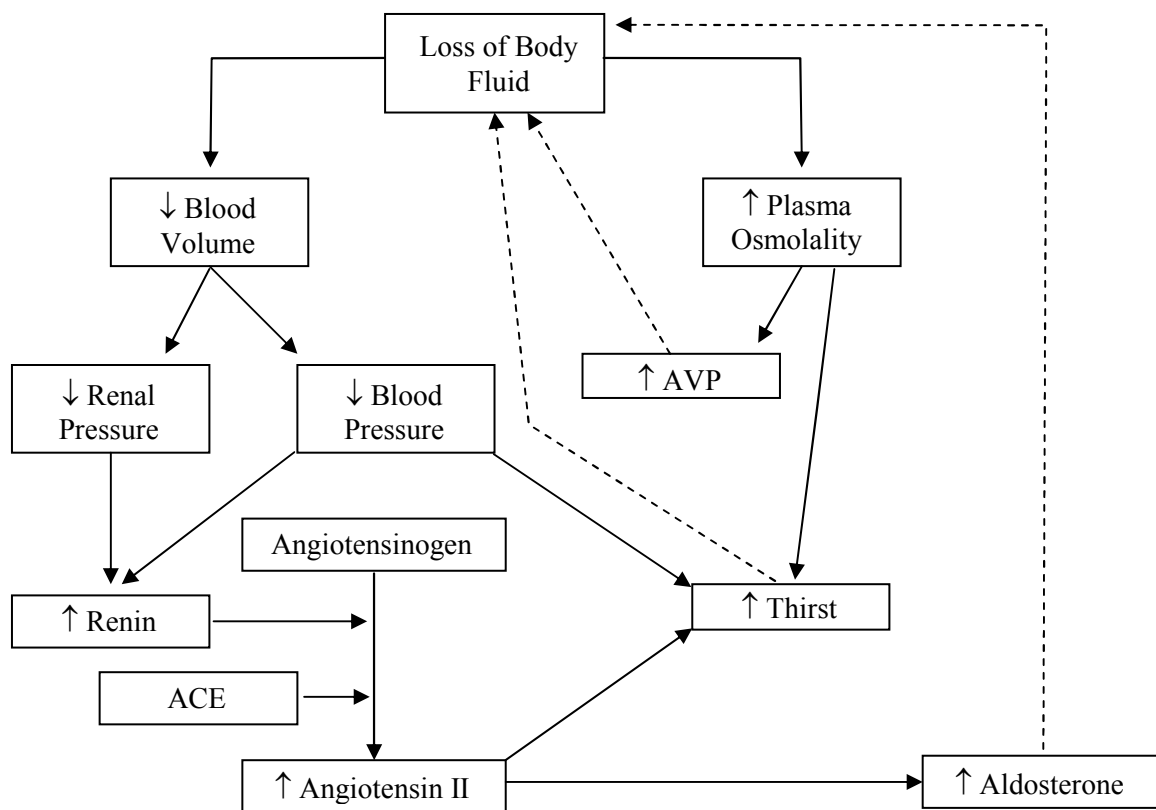
When exercise is conducted in the heat, the relative contributions of  $C_v$ ,  $C_d$ , and  $R$  heat losses decrease due to a reduction or equilibration in thermal gradients placing the majority of heat loss on evaporation. Latent heat of vaporization is 2.41 kJ/g water. If an individual is exercising at ~2 L/min oxygen consumption rate (assuming 5 kcal/L  $O_2$ ) at a workrate of 140 W (J/s) in the heat, he/she must lose ~560 J/s of heat. This translates into ~2000 kJ/h or ~840 g/h of sweat assuming all sweat evaporates from the skin and no sweat is lost to the ground. According to Montain et al. (25), this rate is approximately the sweat rate for a 70 kg individual running at a moderate rate in a warm environment (~28°C). The maintenance of sweat rates, especially in the heat, is extremely important for temperature regulation. In hypohydrated individuals, the compromise between cardiovascular function and temperature regulation is broken and sweat rates and skin blood flow are reduced to maintain adequate cardiac output.

Fluid replacement during exercise appears to offset thermal strain caused by dehydration. Armstrong et al. (26) and Montain et al. (1) showed that dehydration prior to exercise leads to excess heat storage due to a reduction in sweat sensitivity when individuals were not allowed to drink fluids during exercise. When individuals were allowed to drink cool water *ad libitum*, heat storage was reduced and sweat sensitivity and cardiovascular function (HR) were restored. Similarly, complete restoration of body fluids during exercise by forced water intake equal to fluid lost during exercise results in uncompromised

cardiovascular function, indicated by cardiac output, stroke volume, and heart rate, and temperature regulation (18). However, it should be noted that, although typically occurring less often than significant hypohydration, research has correlated incidences of hyponatremia during exercise with large quantities of dilute beverages, such as water (27), especially in individuals that are predisposed to excess water intake and inappropriate suppression of arginine-vasopressin (6).

### **Fluid balance regulatory mechanisms**

Fluid balance is regulated by mechanisms involving drinking behavior and dipsogenic drive (thirst) and the regulation of water conserving hormones. The following section outlines the interactive mechanisms involved with fluid balance regulation and provides evidence that these mechanisms, especially increased plasma osmolality, can be exploited during exercise to prevent normal voluntary dehydration. However, before a discussion of potential mechanisms can ensue, exercise induced alterations in plasma homeostasis must be discussed. As indicated in Figure 1, the overall loss of body fluid, whether through hemorrhage or sweat, results in a cascade of events designed to restore blood pressure and body water. The osmolality and sodium content of sweat is lower than plasma making it relatively dilute (28-30). During long duration exercise, sweat losses are high leading not only to a loss of body water but also an increase in plasma osmolality (hyperosmotic hypovolemia) effectively disturbing the equilibrium of this system (28-30).



**Figure 1.** Integrative mechanism regulating body fluid disturbances. (ACE, Angiotensin converting enzyme; AVP, arginine vasopressin) Solid lines represent stimulation and dashed lines inhibition.

### *Regulation of thirst*

The regulation of water intake by thirst involves the coordination of several mechanisms: direct plasma stimulation on the brain, afferent stimulation from baroreceptors, and afferent stimulation by temperature and mechano- and osmoreceptors located in various regions within the gastrointestinal tract. Although severe dehydration can affect the central nervous system directly, most of the plasma monitoring receptors that regulate thirst are located at the base of the brain: the circumventricular organs (CVO). The circumventricular



organs are the neurohypophysis (posterior pituitary), the organum vasculosum of the lamina terminalis (OVLT), the subfornical organ (SFO), and the area postrema (AP). In particular, the OVLT and SFO are sensitive to plasma osmolality changes, whereas the AP is related to pressor mediating responses. Research determined the effect of hyperosmolality on SFO and OVLT activity by determining neuronal activity, particularly expression of an early marker of activity, *c-fos*, following intravenous hyperosmotic solution infusion (31,32). Also, efferent projections from these regions, especially the dorsal cap of the OVLT, regulate vasopressin release from the neurohypophysis. These CVO are also responsive to angiotensin II (ANGII) as indicated by *c-fos* immunoreactivity (32,33). Stimulation of the SFO and, to a lesser extent, the OVLT leads to an increased sensation of thirst and subsequently water intake that seems to be mediated in through muscarinic connections in the anterior 3<sup>rd</sup> ventricle and the supraoptic and paraventricular nuclei of the hypothalamus (SON and PVN, respectively, 34). The SON and PVN are responsible for the release of vasopressin and oxytocin through the posterior pituitary implicating increases in plasma osmolality not only in thirst but also conservation of water by the kidneys.

Hyperosmolality associated with exercise, water restriction, or infusion of hypertonic solutions is associated with an increase in the perception of thirst (35-37). Perceived thirst increases linearly with an increase in plasma osmolality provided the osmolality is above the osmotic threshold predicted by Thompson et al. (35) of approximately 281 mOsm/kg. Maresh et al. (37) support these data indicating an exacerbated thirst in hypohydrated individuals. Of particular interest, especially during exercise, is the rapid reduction in thirst and water intake with the ingestion of dilute fluids even during exercise (36-41). A potential

mechanism behind this phenomenon was demonstrated in recent research conducted by Stricker et al. (39,40) indicating that GI tract stretch receptors and/or hepatic portal osmoreceptors inhibit thirst before significant changes in plasma osmolality. This research is supported by Figaro and Mack in humans (38) who additionally demonstrated that oropharyngeal stimulation reduces thirst similarly to gastrointestinal stretch. In this way, thirst is regulated by the volume of ingested fluid, not by the interior milieu that initially triggered the thirst response. Additionally, there is evidence that, although thirst is immediately reduced despite the fluid ingested, later thirst and drinking behavior is affected by beverage sodium content with higher sodium content driving water intake to a greater extent than water alone (41).

#### *Regulation of hormonal systems*

Voluntary dehydration, together with the normally dilute nature of sweat, causes in a reduction in blood volume and an increase in plasma osmolality and electrolyte concentrations (28-30). The reduction in blood volume and simultaneous increase in plasma osmolality and electrolyte concentrations induce specific counteractive hormonal mechanisms including increases in arginine vasopressin (AVP), plasma renin activity (PRA), and aldosterone (ALD) (35-37). Maresh et al. (37) investigated the relationship between plasma osmolality and fluid regulating hormone changes with body fluid deficits and water replacement in subsequent exercise. In this study, significant hypohydration (-4%) before exercise and the resultant increase in plasma osmolality was not great enough to induce an increase in AVP, ALD, or PRA, but led to an increased perception of thirst. However, when the participants started to exercise in a hypohydrated state in the heat (33°C, 56% RH)

without access to water during exercise, AVP, PRA, and ALD significantly increased compared with when they began exercise euhydrated or hypohydrated and were allowed water during exercise. Fluid intake during exercise also had an independent effect on ALD and PRA when fluid was restricted in exercise even when starting exercise in a euhydrated state. This study indicates that the primary response to hypohydration and increased plasma osmolality is to increase water intake by augmenting thirst; however, when exercise is started in the euhydrated state without subsequent fluid intake, the thirst mechanism remains off and counter-regulatory hormones must increase to continue to conserve body water (37).

Contrary to the above study by Maresh et al. (37), increased plasma osmolality has been associated with higher AVP concentrations when the osmotic threshold ( $\sim 285$  mOsm/kg for AVP) is crossed at rest (35). Further studies by Thompson et al. (36) support this research indicating that plasma hyperosmolality by hypertonic saline (5%) solution infusion results a linear response in AVP concentration. Similar to previously mentioned research, water ingestion ( $\sim 1200$  ml) almost immediately reduced the perception of thirst and AVP concentration. Together, these studies indicate that the mechanisms for thirst and counter regulatory hormones are specific for rest and exercise and appear, at least in exercise, to be independent of water intake with a rapid lowering of thirst and slower hormone response.

### **Fluid intake during and after exercise**

#### *Effect on drinking behavior*

The volume of beverages consumed during and after exercise can be influenced by the composition, temperature, or flavor of the beverage, with carbohydrate/electrolyte, cold, and flavored beverages increasing fluid intake (23,42-47). Bar-Or and coworkers (44,45)

determined that ingestion of a carbohydrate/electrolyte solution during exercise improved fluid balance due to an increase in fluid intake compared with flavored and unflavored water. In fact, the amount of fluid ingested was adequate to completely abolish voluntary dehydration during exercise in the heat (WBGT =  $\sim 30^{\circ}\text{C}$ ). Interestingly, simply flavoring water improves fluid balance during exercise compared with unflavored water (45). These studies support the previous work of Hubbard et al. (23) demonstrating that not only independent effects of flavoring to improved fluid balance during 6 h of walking in the heat, but also beverage temperature. In the study by Hubbard et al. (23), participants ingested  $\sim 800$  ml more water when beverages were served at  $15^{\circ}\text{C}$  compared with  $40^{\circ}\text{C}$  and  $\sim 750$  ml more water when beverage were flavored. Last, greater fluid intake was observed in individuals that typically ingest less fluid during exercise (reluctant drinkers; 47).

After exercise/thermal induced dehydration, beverage composition directly affects fluid intake and hence, fluid balance after recovery (42,46). Nose et al. (42) investigated independent effect of supplemental NaCl ingestion on water intake and urine output (fluid balance). Participants voluntarily rehydrated after exercise with water + placebo caplet or water + NaCl (450 mg) caplet every 100 ml of water. The main outcome of this study was greater fluid intake with supplemental NaCl compared with placebo that may have occurred because of an increase in thirst regulated by an augmented plasma osmolality or sodium concentration. Similarly, Wemple et al. (46) found improved fluid intake when participants were offered a carbohydrate/electrolyte beverage containing 50 mM  $\text{Na}^{+}$  compared with plain water. Again, the authors speculated that the rapid removal of the osmotic stimulus in rehydration with water intake resulted in a lower dipsogenic response. While these studies

indicate fluid intake during and after exercise is influenced by beverage composition, flavor, and temperature, no studies have investigated the effect of preexercise beverage composition on fluid intake during exercise.

#### *Effect on physiologic function*

Beverage composition, flavor, and temperature not only have dramatic effects on fluid intake, and therefore fluid balance, during and after exercise. Beverage composition also appears to regulate fluid intake and water retention through the aforementioned physiologic responses. During exercise, beverages containing significant amounts of sodium regulate the quantity of water lost in urine and influence the compartmentalization of body fluids (48). In a controlled fluid intake trial, participants ingested an 8% carbohydrate solution containing 5, 50, or 100 mM Na<sup>+</sup> before and every 10 min during 4 h of exercise in a thermoneutral environment (~20°C). Although fluid intake was similar in all trials, fluid balance was improved due to a reduction in urine output and overall free water clearance with 100 mM Na<sup>+</sup> compared with both 5 and 50 mM Na<sup>+</sup>. Also, while the 5 mM Na<sup>+</sup> beverage promoted the maintenance of intracellular water volumes, greater extracellular water volumes were observed with increased sodium intake during exercise. The extracellular fluid expansion was the result of significantly greater plasma osmolality observed late in exercise in both the 50 and 100 mM Na<sup>+</sup> trials compared with the dilute fluid intake. These results support those of Vrijens and Rehrer (27) who found that carbohydrate/electrolyte intake during exercise in the heat resulted in lower urine output compared with water intake when fluid was given at a rate equal to sweat losses. Interestingly, one participant in this study became clinically hyponatremic (plasma sodium < 130 mM) during the water only trial, indicating that extra

sodium intake during exercise, despite a possible inappropriate response to low plasma sodium (subject also had low urine output), can alleviate this potentially harmful situation.

Research on fluid intake after thermal/exercise induced dehydration has shown that beverage composition and volume affect hydration status and body water recovery. Optimally, after a short rehydration period (2-3 h), plasma volume and fluid deficit would be completely recovered. Costill and Sparks (49) initially investigated the effects of beverage composition on urine output and plasma volume recovery and found that a carbohydrate/electrolyte solution expedited plasma volume recovery and reduced urine output compared with water in rehydration. These results were replicated by Gonzalez-Alonso et al. (50). However, Gonzalez-Alonso et al. (50) also reported improvements in fluid balance (percent water retained) with a carbohydrate/electrolyte beverage compared with water intake and higher serum osmolality, indicating a potential mechanism for the increase in plasma volume and reduction in urine output. In an attempt to delineate independent effects of the carbohydrate and sodium content of the beverage on rehydration, Maughan et al. (51) provided water containing glucose, sodium, or both in equal volumes to water losses during thermal/exercise induced dehydration over a 30 min period. Over the next 6 h, cumulative urine output was greater with carbohydrate alone compared with both trials containing sodium (60 mM Na<sup>+</sup>) resulting in significantly lower percent body water retention (55% vs. 75%). These results were expanded by Shirreffs et al. (52) who demonstrated that in order to completely replace body water after exercise/thermal induced dehydration, 150% of water losses in dehydration must be ingested containing at least 100 mM Na<sup>+</sup>. Meals containing

high concentrations of sodium (9,10) cause a similar reduction in urine output, improvement in fluid balance, and expansion of plasma volume to sodium-containing beverages.

Evidence exists that the improvement in fluid balance and expansion of plasma volume during rehydration with beverages containing sodium are caused by higher plasma osmolality and a corresponding increase in water conserving hormone concentrations (9,42,43). Specifically, Maughan et al. (9) found that ingestion of a meal containing a significant sodium load increased plasma ANGII to a greater extent than ingestion of a commercially available sports drink. Nose et al (43) reported an increase in PRA after water and sodium intake compared with water alone. The resultant effect of the hormonal excretion after ingestion of sodium containing beverages would be an increase in water (AVP) and sodium (PRA, ALD, and ANGII) retention and improved net fluid balance after rehydration. The impact of improved fluid balance after rehydration with sodium containing beverages on physical and cognitive performance in subsequent exercise has yet to be determined, although Wong et al. (53) suggests greater endurance performance after rehydration with a carbohydrate/electrolyte beverage.

### **Fluid intake before exercise**

Preexercise hyperhydration (excessive water intake before exercise leading to higher than normal body water content) has been investigated as a potential method to offset voluntary dehydration and counteract cardiovascular and temperature regulation issues associated with the loss of significant body fluids in exercise. Initial studies yielded equivocal results with some reporting significant improvements in temperature regulation (54,55) and others demonstrating no effect (5,56,57). However, a major modifying factor in

these studies seems to be the rate of water ingestion during exercise. Hyperhydration is only beneficial when individuals are allowed to drink water during subsequent exercise, but does not provide additional cardiovascular or temperature regulation advantages when individuals are adequately hydrated before exercise (54,55). Poor cardiovascular control and temperature regulation may be caused by significant dehydration in control trials where water is not allowed during exercise. An increase in water ingestion before exercise may also cause a disadvantageous increase in urine output during exercise.

Studies have investigated the time course of hyperhydration after water and water + glycerol, an osmotic agent, ingestion at rest (58,59). Freund et al. (59) found that ingestion of 1.5 g glycerol/l total body water (TBW; estimated using the deuterium oxide dilution technique) (osmolar load ~777 mOsm) plus 37 ml/l TBW water in 30 min improved fluid balance after 3 hours of rest due to a decrease in urine output and free water clearance compared with a similar volume of water. The improved water retention was more than likely caused by an increased plasma osmolality and concurrently, an increase in AVP concentration, from 30 to 90 min of rest in the glycerol trial (59). Interestingly, the extra body water caused a reduction in ALD that, in addition to the increase in urinary glycerol, resulted in an increase sodium output and osmotic clearance rate. These data support those of Riedesel et al. (58) indicating that a similar glycerol load induced an increase in plasma osmolality and percent water retained after 4 h of rest. Of particular interest is whether active osmotic agents can improve fluid balance and protect against cardiovascular strain and hyperthermia.



Glycerol hyperhydration before exercise, compared with water hyperhydration, also results in a reduced urine output and expanded plasma volume (60-62), although results are not as consistent as those observed in resting studies (11,63). Additionally, the overall effect of glycerol hyperhydration on measures of cardiovascular strain, sweat rate, and temperature regulation is equivocal. While some studies have reported increased sweat rates or sensitivity and improved temperature regulation (60,61), others demonstrate minimal or no changes in temperature regulation or cardiovascular function compared with water hyperhydration (62-64). Latzka et al. (11) hypothesized that the difference in the studies was due to the rate of water intake during exercise. They found that water and glycerol hyperhydration decreased thermal and cardiovascular strain, but only if adequate water was allowed during exercise. To date, no studies have investigated whether glycerol hyperhydration and the associated increase in plasma osmolality increases *ad libitum* water intake during exercise and provides the additional stimulus to drink compared with simple water hyperhydration.

Although hyperhydration with water or a combination of water and glycerol is interesting, only one study has investigated the effects of other osmotically active substances, such as sodium, given before exercise on fluid balance during exercise. Sims et al. (65) examined the effects of preexercise sodium (high sodium = 164 mM vs. low sodium = 10 mM) hyperhydration (~750 ml water) on measures of fluid balance and performance during exercise in the heat. Although the researchers found augmented fluid balance and plasma volume and marked reductions in urine output, cardiovascular strain and temperature regulation were independent of preexercise sodium load. However, participants were not

allowed to drink water during exercise. As stated previously, benefits of hyperhydration may occur only if water is allowed during exercise.

### **Sodium balance**

The ACSM recognized the importance of replacing not only water during exercise but also electrolytes and recommended that beverages ingested during exercise contain 0.5 to 0.7 g/l (20 to 30 mEq/l) sodium to replace losses in sweat (7). Sweat sodium concentrations typically range from 40 to 60 mEq/l making sweat dilute compared with normal plasma sodium concentrations of approximately 140 mM (28,29,66). Depending on the environment, size and acclimation status of the individual, exercise intensity, and type of clothing worn during exercise, sweat losses can exceed 2 to 3 l/h leading to cumulative sweat sodium losses approaching 3.5 g/h (28,66,67). Research also indicates that sweat sodium concentrations increase as a function of sweat rate, further exacerbating sodium losses during exercise in a hot environment (68). These losses, along with urinary sodium losses, may result in significant sodium depletion during exercise.

Researchers investigating sodium replacement during exercise determined that in order to achieve sodium balance, ingested beverages must contain at least 50 mmol Na<sup>+</sup>/l (48). Sanders et al. (48) found that during 4 hours of exercise in a thermoneutral environment, total sweat sodium losses were 3.5 to 4.4 g. In this study, participants ingested a total of 3.85 l of a carbohydrate-electrolyte beverage containing 5, 50, or 100 mmol Na<sup>+</sup>/l (or 0.45, 4.5, and 8.9 g total). Sodium losses in sweat, coupled with urinary output, resulted in significant sodium losses with the 5 mmol/l beverage that were almost completely reversed by ingesting a beverage containing additional sodium (> 50 mmol/l). Higher concentrations

of sodium in the ingested beverages led to an expansion of plasma volume and a reduction in free water clearance, indicating a potential mechanism for the maintenance of cardiovascular function, even though heart rate responses in exercise were identical.

A major question that exists is whether the inclusion of sodium in hydration fluids is necessary to prevent hyponatremia (plasma sodium content  $< 130$  mM) and associated health risks. Although Sanders et al. (48) reported little effect of beverage sodium content on plasma sodium responses in exercise, Vrijens and Rehrer (27) indicated that ingestion of sodium-free beverages, given at a rate to offset fluid losses during exercise in the heat, results in significant plasma sodium reductions compared with typical carbohydrate/electrolyte beverage ( $[\text{Na}^+] = 18$  mmol/l). Other researchers claim that overzealous fluid intake coupled with an inappropriate AVP response leads to dilutional hyponatremia (6). Typically, runners who become hyponatremic either maintain or gain body mass during long races providing evidence that over consumption of dilute beverages may be responsible for drastic changes in plasma sodium content, not poor sodium balance or intake (6,69,70). Noakes et al. (6) reported no incidences of clinically significant hyponatremia ( $[\text{Na}^+] < 130$  mM) in 2135 participants from 8 different endurance events (4 Ironman triathlons, 3 marathons, and 1 109-km cycle tour) if significant dehydration occurred ( $> 3\%$ ). While even experienced runners can become hyponatremic, less experienced runners are at a greater risk due to a longer exercise time in long distance races (71). Together, this research indicates that during long duration exercise, ingesting dilute beverages to maintain mild levels of dehydration ( $< 2\%$ ) is probably not detrimental, but sodium needs to be included in beverages for individuals who

typically over drink or are predisposed to inappropriate counter-regulatory feedback (low AVP in exercise).

In a recent review, Sharp (67) compiled several studies with similar dehydration/rehydration protocols to evaluate the independent effects of water and sodium-containing beverages on fluid balance after rehydration. In his review, the percent rehydration (change in body mass from pre to post rehydration period) was positively correlated ( $R = 0.81$ ) to the volume (slope =  $0.021 \text{ ml}^{-1}$ ) and sodium content (slope =  $0.406 \text{ l/mmol}$ ) of the beverage ingested. What is not known is the relationship between predicted sodium in the rehydration beverage at a given volume and the actual sodium lost during dehydration. In other words, is sodium balance achieved by simply ingesting the same amount of water and sodium lost during dehydration? By using Sharp's example as a guideline (p. 237S; 67), a 75 kg person who is 2.5% dehydrated and ingests 100% of the water lost in exercise would require a beverage with  $93.4 \text{ mmol Na}^+/\text{l}$  ( $\sim 4 \text{ g}$  total sodium). The same individual would lose  $\sim 94 \text{ mmol}$  ( $\sim 2.2 \text{ g}$ ) of sodium, or about half as much that is required in the rehydration beverage, if a normal sweat sodium concentration of  $50 \text{ mmol/l}$  is assumed (29). If this individual wanted to ingest 150% of the fluid lost in dehydration, the total sodium required in the rehydration beverage would decrease to  $\sim 44.9 \text{ mmol/l}$  ( $\sim 1.9 \text{ g}$ ). What becomes apparent is that while sodium in a rehydration beverage is important when limited quantities are available, dilute beverages can produce similar results if large amounts are ingested. However, as Sharp (67) points out in the review, additional variables, such as beverage temperature, electrolyte content, osmolality, and macronutrient profile, may change

the overall behavior of a rehydration beverage *in vivo*. Large quantities of dilute beverages may not be convenient prior to subsequent exercise because of the likelihood of diuresis.

Although acute dilutional hyponatremia is an important issue to consider, chronic sodium deficiency associated with low sodium intake and daily physical activity resulting in significant sweat losses may be equally important. Dilutional hyponatremia is preventable within the time frame of the competition, whereas chronic sodium imbalances may not be predictable. The daily reference intake (DRI) for sodium is 2.4 g/d. As clearly demonstrated above, the amount of sodium lost in sweat alone during exercise can exceed this amount on a daily basis. Studies by Ray et al. (10) and Maughan et al. (9) investigated the effect of high sodium-containing meal ingestion (chicken noodle soup = 1.4 g and chili-rice = 11.3 g, respectively) on the restoration of fluid balance after thermal/exercise induced dehydration. Percent body water recovery after rehydration was improved after meal ingestion in the study by Maughan et al. (9) possibly because of a higher rate of water intake (150% vs. 100% in ref. 10). However, urine output was lower and percent plasma volume recovery was higher after the meal ingestion compared with dilute beverage ingestion without significant differences in plasma sodium responses. These studies indicate that 1) large quantities of sodium can be ingested, or lost, without significant changes in sodium balance and 2) sodium ingestion helps to restore plasma volume rapidly potentially benefiting subsequent exercise performance. What is not clear is whether replacing anticipated sodium losses before exercise can prevent acute dilutional hyponatremia associated with excessive *ad libitum* water intake when sweat sodium losses are high.

## **Beverage composition effects on gastric emptying and intestinal absorption**

### *Gastric emptying*

Much research has been conducted to identify factors that may affect the rate of gastric emptying including the volume, osmolality, electrolyte and macronutrient content, temperature, and overall calorie content of the ingested substance. Initial research was conducted to determine whether macronutrient profile, percentage and types of carbohydrates, fats, or proteins, significantly affect the rate of food emptying from the stomach. Hunt and Stubbs (72) published a review investigating the role of calorie content (kcal/ml meal) and meal volume on the rate of gastric emptying and attempted to establish equations to estimate gastric emptying rate. They determined that as long as the meal volume was between 300 and 500 ml, gastric emptying rate was curvilinear and almost completely dependent on the calorie content of the meal, regardless of the macronutrient profile. Subsequent studies have supported the conclusions of Hunt and Stubbs (72-75), although some evidence exists that protein content can affect gastric emptying (76).

Most of the aforementioned studies recognized that electrolyte and osmolar load may have an effect on gastric emptying rate, and so were controlled. Exercise research has a particular interest in beverage osmolality due to the high carbohydrate and electrolyte content in commercially available carbohydrate/electrolyte beverages. Significant slowing of fluid delivery to the intestine because of high osmolar loads could result in delayed hydration and problems with cardiovascular function and temperature regulation, even though fluid intake is adequate. Costill and Saltin (77) determined that several factors consistent with typical beverages ingested in exercise affect gastric emptying rate. They showed that gastric

emptying was slowed by higher glucose content independent of volume and electrolyte concentration and expedited by lower solution temperature, greater volume ingested, and higher exercise intensity independent of glucose concentration and beverage volume. However, what this study does not investigate is the independent effects of calorie content and osmolar load on rates of gastric emptying. Further investigations have indicated that, regardless of electrolyte content or overall osmolality, caloric density generally predicts gastric emptying rate (78,79) although there is some evidence that gastric emptying rates are identical between water and commercially available carbohydrate/electrolyte beverages despite large differences in calorie content (80,81). Lastly, in support of Costill and Saltin (77), Mitchell et al. (82) showed that the increasing beverage volume also increases the rate of gastric emptying.

#### *Intestinal absorption*

Whereas the rate of gastric emptying is important for the delivery of ingested fluids to the intestine, the rate of absorption and assimilation of water is determined by the rate of absorption of the fluids across the intestinal lumen. In a series of studies, Gisolfi et al. (79,83,84) investigated the effect of beverage osmolality and sodium content on intestinal absorption. Overall, they determined that in the first 25 cm of the intestine, hypertonic solutions reduced solute flux into the lumen, but slowed water absorption compared with water and that the addition of extra sodium to beverages containing 6% carbohydrate did not affect either solute or water absorption (83,84). In later intestinal segments (25 – 50 cm), hypertonic beverages maintained higher water absorption whereas absorption after water ingestion fell significantly (84).

The research above is consistent with previous theory that glucose absorption may occur resulting in solvent drag and thus sodium absorption through the paracellular pathway rather than the transcellular pathway (85). If sodium and glucose absorption progressed through the transcellular pathway by the shared glucose transporter, the addition of extra sodium to the beverage would speed the absorption of glucose and water through the intestinal brush border. However, Fordtran (85) makes a particular note that the intestinal lumen must contain adequate glucose in order to promote absorption of both water and sodium. Current research using an in vivo dog model indicates that intestinal water and sodium transport requires intraluminal glucose (86). These studies indicate that although gastric emptying rate may be slower with the addition of glucose due to a higher caloric content, hydration beverages need to have sufficient glucose in order to expedite water and sodium uptake in the intestine by increased paracellular, and possibly transcellular (shared sodium and glucose transporter), uptake.

### **Implications of exercise-induced dehydration on performance**

#### *Physical performance*

Dehydration not only appears to produce significant problems with cardiovascular function and temperature regulation but may also induce severe declines in cognitive and physical performance. Physical performance, in both anaerobic (87-89) and aerobic (3,90) exercise, are reduced in a dehydrated state, even as mild -1.5%. Performance decrements in aerobic exercise seem to be more pronounced than anaerobic trials. Armstrong et al. (3) found that, in events ranging from 1,500 to 10,000 meters, endurance performance was impaired after diuretic-induced dehydration of ~2% body mass. Additionally, they reported



that performance in the longer races seemed to be affected to a greater extent than that in shorter races. Cheuvront et al. (90,91) supports this theory demonstrating reduced performance in an aerobic time trial (work in a given amount of time) when dehydrated (~3%) whereas anaerobic performance (Wingate test) was preserved in a dehydrated state. Some research has indicated that the difference in endurance performance may be due to a lower lactate threshold in the hypohydrated state (87,92). The reduction in performance during longer duration exercise may be the result of reductions in cardiac function or increases in sympathetic nervous system activation. Also, impaired endurance performance may be the result of a combination of hypohydration and environment with performance decrements only observed when exercise is conducted above normal room temperature (20°C; 90).

Impairments in short-term, high-intensity physical performance with dehydration are not as well studied as those observed with endurance performance. Webster et al. (87) found reduced upper body strength and anaerobic power and capacity after ~5% body mass loss in college wrestlers. Similarly, a reduction of 1.5% body mass resulted in a significant decline in 1 repetition max in the bench press (89) even though a completely different dehydration technique was used (sauna exposure vs. exercise in a rubber suit). However, mean and peak power and fatigue index during a 15 s Wingate was preserved in a hypohydrated state (~3% body mass loss) resulting from passive heat exposure (92) while a 6 min isokinetic arm crank test after ~4.5% body mass loss was severely impaired (88). The only common thread in these studies seems to be exercise modality: arm exercises tend a reduction in exercise performance in the hypohydrated state (87-89), whereas leg exercises do not (87,91).

### *Cognitive Performance*

Cognitive performance during fatiguing/dehydrating exercise is not well studied. Early research indicates that progressive dehydration results in reduced performance in serial addition, trail-marking, and word recognition tasks (93) with as little as 1 to 2 % dehydration. Sharma et al. (94) also found differences in psychomotor performance (hand eye coordination) at similar states of dehydration. Performances in various other mental challenges including reaction time, short term memory, and perceptual discrimination have been shown to decrease in a dehydrated compared with euhydrated state (95,96). Neurophysiological function assessed by the P300 (auditory event-related potentials) declined after 1 hour of exercise at ~66%  $\text{VO}_{2\text{peak}}$  indicating a slowing of cognitive processing, but, when hypohydrated, no effect was observed in the P300 (97), indicating an effect of exercise independent of hydration status. Interestingly, hyperhydration seems to further improve cognitive performance (especially long-term memory) compared with both euhydrated and dehydrated states (98). Dehydration during exercise also causes an increase perceived tiredness and fatigue that may exacerbate cognitive decrements associated with simple reductions in body water (95,96). However, acute exercise may actually increase cognitive performance in perceptual tasks (reaction time, anticipation-coincidence tests, Stroop Word Color Interference) due to significant exercise-induced mental facilitation (99-101).

New computerized tests that rapidly and objectively evaluate higher level cognitive processing (Stroop Word/Color choice test; Western Psychology, Inc.) have been developed but have yet to be studied extensively during exercise. Further research regarding both physical and cognitive performance is warranted, especially research that investigates the

interaction between fluid intake, dehydration, and electrolyte replacement during exercise under compensable heat stress.

## **Conclusions**

Water intake during exercise, especially when evaporative heat losses are high, is necessary to reduce cardiovascular and thermal strain. Although our bodies naturally house regulatory mechanisms to increase fluid intake and reduce water losses, these mechanisms are not adequate during exercise. Recent research has attempted to prevent voluntary dehydration by changing the composition, flavor, or temperature of ingested beverages, increase the amount of fluid ingested and the rates of gastric emptying and intestinal absorption, and reduce volume dependent loss of dipsogenic drive. While these techniques reduce the incidence of voluntary dehydration, exercising individuals do not always have access to optimal rehydration beverages. Hyperhydration before exercise with water or combinations of water and osmotically active substances (i.e., glycerol) promotes adequate hydration during exercise, but cardiovascular and temperature regulatory benefits are only observed when adequate water is forced during exercise. Whether mild preexercise hyperhydration with beverages containing other osmotically active substances, such as sodium, improves fluid balance during endurance exercise is not known. Also, whether compositional effects on augmented fluid balance are adequate to preserve cardiovascular function and evaporative heat dissipation (sweat rate) during exercise under compensable heat stress has yet to be determined. Last, whether these beverages can influence the rate of change in thirst and plasma constituents compared with water containing equal amounts of sodium is not known.

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### CHAPTER 3. EFFECT OF PREEXERCISE BEVERAGE INGESTION ON FLUID BALANCE AND EXERCISE TOLERANCE

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#### Abstract

Ingestion of beverages containing electrolytes before exercise may stimulate *ad libitum* water intake and lower urine production thus promoting fluid balance during exercise. In order to study the efficacy of 3 beverages on fluid balance, 20 healthy people (10 male, 10 female;  $24 \pm 3$  y) exercised at  $57 \pm 4\%$  (means  $\pm$  SD)  $\text{VO}_{2\text{peak}}$  in a thermoneutral environment ( $\text{WBGT} = 16.2 \pm 1.6^\circ\text{C}$ ) for 90 min, 45 min after ingesting 355 ml of either chicken noodle soup (CNS; 167 mM  $\text{Na}^+$ ), a carbohydrate/electrolyte beverage (CE; 16 mM  $\text{Na}^+$ ), or water (WATER). Water intake during exercise was allowed *ad libitum* except in a second soup trial (CNS/R) where water was given at times and volumes equal to CE. After 90 min of exercise, participants completed a performance task consisting of time to finish 30 min of work at  $60\%\text{VO}_{2\text{peak}}$ . Fluid balance was enhanced in CNS and CNS/R compared with WATER ( $-268 \pm 414$  g and  $-328 \pm 500$  g vs.  $-654 \pm 577$  g and  $-477 \pm 596$  g, resp.;  $p = 0.001$ ) due to increased water intake in CNS, CE, and CNS/R and improved water retention in CNS. A rise in plasma osmolality occurred after ingestion of chicken noodle soup that persisted throughout exercise. The increase in plasma osmolality was independent of plasma sodium concentration. Urine osmolality increased in CNS and CNS/R because of a reduction in free

water clearance ( $-1.2 \pm 0.7$ ,  $-0.8 \pm 1.0$ ,  $-0.5 \pm 1.0$ , and  $-0.4 \pm 1.3$  g/min for CNS/R, CNS, CE, and WATER, resp.). Heart rate, systolic and diastolic blood pressures, rectal temperature, and thirst responses were not different between trials. Physical performance was not different by trial ( $p = 0.4$ ). Chicken noodle soup ingested before exercise improved fluid balance due to increased water intake and reduced urinary water loss. The improvement fluid balance was probably the result of higher plasma osmolality before and throughout steady state exercise.

## Introduction

Research performed in our laboratory suggests that ingestion of only 350 ml of chicken noodle soup ( $167 \text{ mmol Na}^+/\text{l}$ ) after exercise/thermal induced dehydration expedites recovery of plasma volume compared with an equal quantity of water or commercially available carbohydrate/electrolyte beverage (1). Beverages containing high concentrations of electrolytes, especially sodium, may also promote fluid retention by reducing water losses in urine (2-5). Although fluid retention is important, promoting additional *ad libitum* fluid intake during and after exercise may be equally important to maintain positive fluid balance (6-9). However, consuming dilute beverages during or after exercise may reduce *ad libitum* fluid ingestion (6-9) and increase net sodium losses (5,10,11), resulting in minimal plasma volume replacement and voluntary dehydration. Fluid imbalance and dehydration exacerbate cardiovascular decline, thermoregulatory strain, and physical performance decrements during exercise (12-19).

Preexercise hyperhydration may be a potential approach to improve cardiovascular function and temperature control during exercise. These preexercise hyperhydration studies

have yielded equivocal results with some studies reporting a reduced thermal strain (20,21) and others demonstrating no effect (22-24). Because water intake prior to exercise also increases water losses in urine, recent studies have used glycerol, a readily available osmotic agent, to promote body fluid expansion and water retention (25-27). The effect of glycerol hyperhydration prior to exercise on thermal stress and sweat rate is unclear (26,28,29,30). What remains unknown is whether mild hyperhydration with a beverage containing osmotically active agents (such as electrolytes) has similar water retention qualities and increases *ad libitum* water intake during exercise by increasing thirst. The optimal preexercise beverage would provide a continued thirst stimulus, reduce urinary water losses, and, consequently, increase available body water

This study was conducted to determine if ingesting electrolyte-containing beverages before exercise increases plasma osmolality effectively stimulating *ad libitum* water intake, reducing urinary water losses, and thus promoting improved whole body fluid balance. Secondly, we wanted to determine whether any improvements in fluid balance were the result of increased *ad libitum* water intake, decreased urine output, or both. Last, we determined whether increased body water after ingesting electrolyte-containing beverages improved cardiovascular function, temperature control, and performance. We hypothesized that ingestion of beverages containing high concentrations of electrolytes 45 min before exercise increases *ad libitum* water intake and reduces urine output leading to improved fluid balance. We further speculated that improved fluid management is the result of higher plasma osmolality before and throughout 90 min of steady state exercise. However, because

exercise was in a thermoneutral environment where thermal strain is minimal, fluid balance will not influence cardiovascular function, temperature regulation, or physical performance.

## **Methods**

### *Participant Characteristics*

Twenty healthy, college-aged ( $24 \pm 3$  y,  $174.4 \pm 9.3$  cm, and  $68.8 \pm 11.9$  kg; means  $\pm$  SD) men and women ( $n = 10$  each) of varying fitness levels ( $\text{VO}_{2\text{peak}} = 51.2 \pm 9.8$  ml/kg·min) volunteered to participate in this study. Physical characteristics separated by gender are located in Table 1. Prior to any physical testing, participants completed a medical history questionnaire that was reviewed and approved by the primary investigators. The study was approved by the Iowa State University Institutional Review Board and all participants gave informed, written consent.

### *Preliminary Testing*

Following initial study consent, weight and height were measured and participants completed a graded exercise test to exhaustion on an electronically braked cycle ergometer (Lode BV, Groningen, The Netherlands) to determine peak oxygen uptake ( $\text{VO}_{2\text{peak}}$ ). The incremental, graded exercise test began at 50 and 40 W for men and women, respectively, and workrate was increased by 50 and 40 W, every 3 min until participants reached volitional fatigue. Respiratory gases were analyzed with computer-interfaced oxygen and carbon dioxide analyzers calibrated with standard gas mixtures (Physio-dyne Instrument Corp., Quogue, NY).

### *Experimental Protocol*

Four trials were completed by the participants in a semi-randomized, counterbalanced order separated by at least 1 week. The trials differed by the beverage ingested 45 min before exercise and the amount of water consumed during exercise. The beverages ingested before exercise were chicken noodle soup (CNS), commercially available carbohydrate/electrolyte beverage (CE), and commercially available bottled, distilled water (WATER). All beverages were served at temperatures that they are normally consumed (CNS = 120°F, CE = 40°F, WATER = 68°F). Table 2 gives the nutrient composition of the experimental beverages. Participants were allowed to drink water (same commercially available bottled, distilled water as above) during exercise *ad libitum* except in a second chicken noodle soup trial (CNS/R) where water intake was regulated by volume and time in order to mimic the CE trial. Three-day diet and physical activity diaries were kept before the first trial and replicated before subsequent trials. Participants were also asked to drink at least 1 extra liter of water, fast for at least 10 h, and refrain from strenuous exercise the day before each trial.

Upon entering the laboratory, subjects voided and supplied a urine sample. A rectal thermometer (YSI 401, Dayton, OH) was inserted to a depth of 10 cm past the anal sphincter. Finally, a heart rate monitor (Polar, Electro Oy, Finland) was affixed. Nude body mass was recorded to the nearest 0.05 kg (Befour, Inc, Saukville, WI). After a Teflon indwelling catheter was inserted into an antecubital vein, participants rested quietly for 10 min before a resting heart rate, blood pressure, and rectal temperature were recorded. Before the resting blood sample, participants also indicated their current rating of perceived exertion (RPE) and thirst (Likert scale 1-9, 9 = very, very thirsty). After a resting blood sample was drawn, participants were given 355 ml of the designated experimental beverage and rested quietly in

a seated position for 35 min. Three ml of sterile saline was infused after each blood draw to keep the catheter patent. All blood samples were taken without stasis and were placed in potassium EDTA ( $K_3EDTA$ ; BD Biosciences, San Jose, CA) collection tubes. Hematocrit (Hct) and hemoglobin (Hb) concentration were measured immediately, the remaining blood was centrifuged at  $400 \times g$  for 10 min, and resultant plasma stored at  $-20^\circ\text{C}$  until further analyses could be run.

After 35 min of rest, participants were reweighed nude and rested on the cycle from 40-45 min after ingestion of the experimental beverage during which time all pre-ingestion (Pre-I) measurements were retaken. A pre-exercise (Pre-Ex) blood sample was drawn and exactly 45 min after ingestion of the experimental beverage, the participants began 90 min of steady state exercise at  $57 \pm 4\%$   $VO_{2\text{peak}}$  in a thermoneutral environment ( $16.2 \pm 1.6^\circ\text{C}$ ). Every 30 min (EX30, EX60, and EX90) during the steady state exercise, RPE, thirst, rectal temperature, and heart rate were recorded. Expiratory gases were sampled during the last 5 min of each 30-min interval and used to calculate substrate oxidation during exercise by stoichiometric equations (31). Blood samples were drawn at each 30-min interval and treated similarly to Pre-I and Pre-Ex samples. Blood pressure was also measured during the last 5 min of the steady state exercise period.

After 90 min of steady state exercise, participants dismounted the cycles, towed dry, weighed nude, remounted the cycles, and began the exercise tolerance task. The total amount of time between the steady state exercise and the subsequent physical performance task was approximately 5 min. The performance task was the time to finish the work equivalent to 30 min at 60% of  $VO_{2\text{peak}}$ . Participants were given no encouragement or indication of time or

RPM during the performance trial except verbal acknowledgement of when they had completed 25, 50, 75, and 100% of the time trial. After the performance task (Post-TT), dry, nude body mass and resting blood pressure were measured and total urine volume was collected.

### *Biochemical Analyses*

Blood samples were analyzed in triplicate for Hb concentration by cyanmethemoglobin spectrophotometry (Stanbio, Boerne, TX) and hematocrit by microcapillary centrifugation. Hematocrit values were corrected for trapped plasma volume between red blood cells (0.96) and venous-to-total body Hct ratio (0.91; 32). Percent plasma volume change was calculated using the equations of Dill and Costill (33) with Pre-I as a reference. Plasma samples were analyzed for plasma osmolality and sodium and glucose concentrations. Urinalysis consisted of total urine volume measured Post-TT and osmolality, specific gravity, and electrolyte concentrations measured Pre-I and Post-TT. Plasma and urinary osmolalities were measured by freezing point depression (Westcor, Inc., Logan, Utah) and sodium concentrations were measured by flame photometry (Cole-Parmer, Chicago, Ill.). Plasma glucose concentration was measured by enzymatic spectrophotometric assay (Stanbio Laboratory, Boerne, TX) and urine specific gravity was determined by hand-held spectral refractometry (Leica Microsystems, Inc., New York). All plasma and urine measurements were performed in duplicate.

### *Calculations*

Fluid balance during the entire trial was used as an indicator of beverage effectiveness to augment water intake during exercise and reduce water losses in urine. Equation 1 shows

the calculation of fluid balance where  $BM_{Pre-I}$  is the initial body mass,  $BM_{Post-TT}$  is body mass immediately after the physical performance task before urination, and  $U_{wt}$  (g) is the estimated urine mass (Post-TT urine volume x specific gravity) after the time trial.

$$\text{Fluid Balance (g)} = (BM_{Post-TT} - BM_{Pre-I}) - U_{wt} \quad (1)$$

The efficacy of preexercise beverages to augment water retention independent of water intake during exercise was determined by calculating the percent water retention as shown in equation 2. In this equation, total water ingested is the mass of water ingested (g) during steady state exercise and subsequent physical performance task.

$$\% \text{ water retention} = [(total \text{ water ingested} - U_{wt}) / total \text{ water ingested}] \times 100 \quad (2)$$

Percent dehydration after steady state exercise was calculated as the percent change in body mass from Pre-I to EX90 after adjusting body mass at EX90 for estimated urine loss (urine accumulation rate multiplied by rest and steady state exercise time; 135 min). Percent dehydration after steady state exercise was used instead of whole trial dehydration because of individual differences in time trial performances and water intake during the physical performance task.

The mass of water consumed with each drink and the time at which the drink was taken was recorded during both steady state exercise and subsequent physical performance



task in order to classify drinking behavior by the rate of water intake (g/min), the volume of water per drink (g), and the time between drinks (min).

Rates of solute and water clearance from the plasma to urine, osmotic (OC) and free water (FWC) clearance rates were calculated as shown in equations 3 and 4, respectively (34). In these equations, mean urine accumulation rate ( $V$ ; g/min) was determined by dividing  $U_{wt}$  by total experimental time (rest + steady state + physical performance times). In order to simulate the conditions under which the urine sample was obtained (one urine sample collected after entire trial was completed; Post-TT), an integrated mean plasma osmolality ( $POsm_{ave}$ ) was calculated.

$$OC \text{ (g/min)} = V \times UOsm / POsm_{ave} \quad (3)$$

$$FWC \text{ (g/min)} = V - OC \quad (4)$$

### *Statistical Analyses*

Statistics were run on Sigma Stat (Systat Software, Inc., San Jose, CA) statistical software. Pre-trial indices of dietary and physical activity control, urine variables (sodium and potassium outputs, specific gravity, osmolality, and volume), fluid balance, % dehydration, % water retention, mean exercise  $VO_2$ , total carbohydrate (TotCHO) and fat oxidation (TotFAT), physical performance time, mean work accumulation rate in the physical performance task, and mean wet-bulb globe temperature (WBGT) were analyzed using one-way repeated measures analyses of variance (ANOVA). One male participant was unable to complete the prescribed amount of work during the physical performance task so his data for

all 4 trials were excluded ( $n = 19$ ). Water intake, drinking behavior, plasma variables (plasma volume, glucose, sodium, and osmolality), RER, carbohydrate ( $\text{CHO}_{\text{ox}}$ ) and fat oxidation ( $\text{FAT}_{\text{ox}}$ ) rates, blood pressure, heart rate, rectal temperature, and rating of perceived exertion and thirst were subjected to two-way repeated measures ANOVAs. Significant trial, time, and/or time by trial interaction effects were evaluated further using Holm-Sidak post hoc analyses where appropriate. Ratings of perceived thirst were added after the start of the study and complete data was collected on 13 of the 20 participants. Interior standard deviation bars have been removed to prevent obscuring internal data points. All values are reported as means  $\pm$  SD and statistical differences were declared if  $p < 0.05$ .

## Results

### *Baseline Observations*

Preexercise body mass, urine specific gravity and osmolality, and plasma osmolality, sodium concentration, and glucose concentration were not different by trial, indicating adequate pre-trial dietary (food and fluid) and physical activity control ( $p = 0.7, 0.2, 0.5, 0.3, 0.9$ , and  $0.7$ , respectively). Likewise, rating of perceived thirst and rectal temperature were similar before ingestion of the experimental beverage ( $p = 0.2$  and  $0.3$ , respectively).

### *Substrate Oxidation*

Mean  $\text{VO}_2$  and  $\%\text{VO}_{2\text{peak}}$  during state exercise was similar for all trials ( $p = 0.2$  and  $0.13$ , respectively). Carbohydrate and fat oxidation rates were independent of trial ( $p = 0.4$  and  $0.6$ ) and time by trial interaction ( $p = 0.3$  and  $0.14$ ), respectively. However, a typical increase in  $\text{FAT}_{\text{ox}}$  and decrease in  $\text{CHO}_{\text{ox}}$  was observed as during steady state exercise ( $p <$

0.001 for both). Total carbohydrate and fat oxidized during steady state exercise was also independent of trial ( $p = 0.4$  and  $0.7$ , respectively).

### *Fluid Balance*

Total water intake (Table 3) was greater after ingestion of CNS ( $1214 \pm 589$  g) and CE ( $1065 \pm 657$  g) compared with WATER ( $862 \pm 541$  g) because of an increased rate of water intake especially noticeable during the physical performance task. The additional total water intake with CNS was due to an increase in the volume of water ingested with each drink and a decrease in the time between drinks (Table 3). Differences in total water intake with CE occurred primarily because of an increased rate of water intake during the physical performance task. The small increases in the volume of water ingested with each drink and time between drinks for CNS compared with WATER were cumulative throughout the metabolic and physical performance phases of exercise showing significance only when summed into total behavior. Perceived thirst was not different for any trial at any time point (Figure 1).

Urine output was similar after each trial (Table 4). However, urine specific gravity in the two CNS trials was significantly higher than in the WATER and CE trials. Urinary sodium and potassium concentrations were also higher in CNS regardless of the amount of water ingested during exercise (*ad libitum* vs. regulated; Table 4). Osmotic clearance was similar in the 4 trials ( $1.9 \pm 0.7$ ,  $1.9 \pm 0.8$ ,  $1.9 \pm 0.9$ , and  $2.2 \pm 0.9$  g/min for WATER, CE, CNS, and CNS/R, respectively). However, calculated FWC rates showed a graded effect depending on water intake and electrolyte concentration of the experimental beverage. The CNS/R trial (regulated water intake and high solute concentration;  $-1.2 \pm 0.7$  g/min) showed

significantly lower free water output compared with WATER (low water intake and low solute concentration;  $-0.4 \pm 1.3$  g/min). Beverages ingested before exercise that contained any electrolytes with ad libitum water intake during exercise produced intermediate results ( $-0.8 \pm 1.0$  g/min and  $-0.5 \pm 1.0$  g/min for CNS and CE, respectively). Small reductions in FWC with significantly greater water intake in CNS caused a greater percent water retention after CNS compared with WATER ( $80 \pm 25\%$  vs.  $61 \pm 36\%$ , respectively; Figure 2).

Fluid balance after 90 min of steady state exercise and subsequent physical performance task was improved after CNS compared with WATER even after restricting water intake by  $\sim 160$  ml in CNS/R ( $-268 \pm 414$  g and  $-328 \pm 500$  g vs.  $-655 \pm 577$  g for CNS and CNS/R vs. WATER; Figure 3). Percent dehydration prior to the onset of the time trial was also higher in CNS compared with WATER ( $-0.22 \pm 0.52\%$  vs.  $-0.57 \pm 0.59\%$ , respectively; Figure 4).

#### *Plasma Constituents*

Plasma osmolality was higher in CNS compared with both WATER and CE (effect of trial  $p = 0.003$ ; Figure 5). The effect of CNS began 45 min after ingestion and persisted throughout steady state exercise (time by trial interaction  $p < 0.001$ ;  $p < 0.05$  at Pre-Ex, EX60, and EX90 compared with WATER and CE; Figure 5). However, the effect of beverage composition on plasma osmolality was independent of plasma sodium concentration; no effect of trial, time or time by trial interaction exists ( $p = 0.2$ ,  $0.2$ , and  $0.7$ , respectively; Figure 6). Despite marked differences in plasma osmolality and fluid balance in CNS, plasma volume responses were similar for all trials with a normal negative plasma volume shift with exercise (time effect;  $p < 0.001$ ). An effect of time ( $p < 0.001$ ) and trial by

time interaction ( $p < 0.001$ ) was observed for plasma glucose concentration due to a typical glucose response curve in CE with a small rise in plasma glucose before exercise and slight insulin/exercise induced hypoglycemia during steady state exercise ( $p < 0.05$  compared with resting values; Figure 7). Plasma glucose concentration was also lower in CE for at least 60 min during exercise compared with WATER and after 30 min of exercise compared with CNS ( $p < 0.05$ ; Figure 7).

#### *Temperature Regulation, Cardiovascular Control, and RPE*

Rectal temperature response across time was not different by trial (interaction,  $p = 0.11$ ; Figure 8). As expected, however, an effect of time on rectal temperature was observed ( $p < 0.001$ ). Rectal temperature decreased during rest then increased significantly during exercise after each 30-min interval ( $p < 0.05$ ). Although heart rate and systolic, diastolic, and calculated mean arterial pressures showed typical responses during exercise (effect of time  $p < 0.001$  for all variables), only heart rate showed an effect of trial with CNS/R resulting in a lower heart rate compared with all other trials ( $p = 0.01$ ). None of the cardiovascular responses showed an interaction of trial and time. A trial by time interaction exists for RPE ( $p < 0.001$ ) due to a significant increase in RPE during exercise compared with rest and significantly greater perceived exertion in CNS compared with CNS/R throughout exercise. Heart rate and RPE responses are easily explained by experimental protocol. The CNS/R trial always occurred after the CNS trial.

#### *Physical Performance Time*

Mean work accumulation during the physical performance task was  $271.0 \pm 78.5$  kJ. The mean rate of work accumulation was not different between trials ( $171.9 \pm 57.0$ ,  $179.0 \pm$

59.2,  $171.6 \pm 60.4$ , and  $176.3 \pm 57.8$  W for WATER, CE, CNS, and CNS/R, respectively;  $p = 0.3$ ). As a result, physical performance time was independent of beverage ingested prior to exercise and water intake during exercise ( $27.6 \pm 9.6$ ,  $25.9 \pm 5.7$ ,  $27.8 \pm 9.0$ , and  $26.8 \pm 7.7$  min for WATER, CE, CNS, and CNS/R, respectively;  $p = 0.4$ ).

## Discussion

Three-hundred fifty-five ml of chicken noodle soup, 45 min before exercise almost completely reversed voluntary dehydration normally observed after ~90 min of exercise in a thermal neutral environment. Typical voluntary water replacement during exercise is approximately 70% when allowed water *ad libitum* during exercise (35,36). We observed lower than expected water replacement rates during the metabolic phase of CE and WATER (53% and 48%, respectively) while CNS maintained normal water replacement levels (68%). The additional water replacement with CNS indicates that fluid replacement during exercise is normal despite extra fluid intake before moderate exercise in a thermoneutral environment where sweat rates and % dehydration are minimal. To our knowledge, this study is the first to demonstrate that by ingesting a high electrolyte meal before exercise (CNS), fluid balance can be preserved by maintaining normal water intake during exercise after mild preexercise hyperhydration.

The majority of improvements in fluid balance we observed after ingestion of chicken noodle soup were caused by improved water intake that persisted throughout the entire trial. Increased water intake during exercise in CNS is consistent with our first hypothesis and arose from dramatic changes in drinking behavior (Table 3). The rate of water intake was 42% greater after chicken noodle soup compared with WATER. However, a graded effect of

beverage composition was apparent with CE (~10% of CNS electrolytes) enhancing the rate of water intake by ~28% compared with WATER. Although the rate of water intake for the entire trial was the same for CNS and CE, the similarity was because of a higher rate of water intake after CE during the physical performance trial while CNS augmented the rate of water intake during both the metabolic and physical performance phases of exercise. Additionally, chicken noodle soup ingestion increased water intake per drink and lowered the time between drinks by 18% and 25%, respectively, compared with WATER.

Several factors regulate fluid intake during and after exercise. These factors include beverage temperature, flavor, and electrolyte (especially sodium) content (6-9,36). Wemple et al. (8) demonstrated that during recovery from dehydrating exercise (~3% dehydration), beverages containing higher electrolyte concentrations ( $[Na^+] = 50 \text{ mM}$ ) resulted in improved fluid balance after 3 h of recovery compared with water ingestion and an improved dipsogenic response compared with lower electrolyte concentrations ( $[Na^+] = 25 \text{ mM}$ ). These data are supported by Nose et al. (9) who found greater net fluid gain with the addition of NaCl to ingested water during recovery. During exercise, similar increases in fluid intake are noted with beverages containing as low as 18 mM sodium (6,36). While these studies demonstrate that electrolyte ingestion affects fluid intake during and after exercise, only one study has investigated electrolyte supplementation before exercise. Sims et al. (37) examined the effects of preexercise sodium loading (high  $[Na^+] = 164 \text{ mM}$ ; low  $[Na^+] = 10 \text{ mM}$ ) on fluid balance and exercise tolerance in the heat. They found that, although fluid intake before exercise was similar, urine output, fluid balance, and exercise performance was improved by additional sodium in the preexercise beverage. However, because this study did not allow

participants to drink during exercise, it is impossible to determine the efficacy of the beverages to improve water intake and reduce voluntary dehydration during exercise. Hyperhydration research that used water and a combination of water and glycerol have shown that in order to maximize the benefits associated with preexercise fluid intake, water is required throughout exercise (29). In the present study, we demonstrated that ingestion of a beverage containing electrolytes caused a persistent increase in water intake resulting in improved fluid balance during exercise.

Increased water intake after chicken noodle soup ingestion does not completely explain the differences in fluid balance. Although urine production was independent of experimental beverage ingested prior to exercise, water retention was greater after chicken noodle soup (Figure 2), representing a reduction in the amount of urine produced per unit water intake (Table 4). Studies investigating the effects of electrolytes and other osmotically active substances such as glycerol, including a study performed in our laboratory using chicken noodle soup (1), indicate a reduction in urine volume when ingested before or during exercise or during rehydration (2,3,5,9,11,37). Other urinary measures support a reduction in free water clearance that is dependent on both water intake during exercise and the electrolyte concentration of the experimental beverage. The observed increase in urine osmolality and specific gravity (Table 4) indicate that after chicken noodle soup ingestion, either a reduction in urinary water or increase in solute excretion occurred. Calculated osmotic and free water clearance rates indicate that in all trials, water was retained by the kidneys and that higher urine osmolality and specific gravity observed in CNS were due to a reduction in free urinary water excretion even though electrolyte intake in CNS was clearly higher. Interestingly, the



increase in free water clearance only reached significance when chicken noodle soup was ingested and water intake during the trial was restricted by ~160 ml (CNS/R vs. WATER). Unrestricted water intake, coupled with the high electrolyte content of the chicken noodle soup, produced an intermediate effect on urinary water output compared with WATER and CE (lower water intake and electrolyte content). This demonstrates that beverage intake, especially beverages that contain high concentration of electrolytes, before exercise has the propensity to set the renal-vascular/hormonal system into a state of water conservation.

Fluid balance differences were the result a divergence in drinking behavior, water retention, and free water clearance with high electrolyte compared with dilute beverages that most likely occurred in response to higher plasma osmolality that occurred before and lasted throughout exercise (Figure 5). Although we did not measure endocrine responses in this study, past research supports this theory. Thompson et al. (38) demonstrated that when plasma osmolality is above 285 mOsm/kg, small increases in plasma osmolality significantly affect the release of AVP. Maresh et al. (39) also found a tight association between plasma osmolality during exercise in the heat and AVP, plasma renin activity, aldosterone, and rating of perceived thirst. Maresh et al. (39) also noted that more water was ingested during subsequent exercise if exercise began in a dehydrated (~4%) compared with a euhydrated state and that perceived thirst and hormonal responses subsided when allowed to drink during exercise compared with complete water restriction. Our study support these data, indicating that higher preexercise plasma osmolality can increase water intake by influencing perceived thirst and water retention and regulating renal/hormonal function. Interestingly, we did not find differences in perceived thirst in this study. However, participants seemed to drink

water in the *ad libitum* trials in order to reach a common level of perceived thirst. Future research should incorporate renal/hormonal measurements in order to fully elucidate the potential mechanism responsible for drinking behavior and water retention.

The observed increase in plasma osmolality with chicken noodle soup ingestion was independent of plasma sodium concentrations before and during exercise. This study is the first we are aware of that shows this response to ingestion of a high sodium beverage before exercise. However, Ray et al. (1) also noted an increase in plasma osmolality independent of plasma sodium concentration with ingestion of chicken noodle soup after thermal/exercise induced dehydration compared with water, but, unlike the current study, the carbohydrate/electrolyte beverage had similar increases in plasma osmolality and sodium concentration compared with chicken noodle soup. Similarly, Maughan et al. (4) did not observe increased plasma sodium or osmolality compared with a carbohydrate/electrolyte beverage during recovery after eating a high sodium meal. Two possible explanations exist for the increased plasma osmolality independent of plasma sodium concentration: either the macronutrients contained in the chicken noodle soup are contributing to the increase in osmolality or chicken noodle soup ingestion causes interstitial water from the gastrointestinal tract to flow into the lumen subsequently reducing available plasma water and increasing plasma osmolality. Future research should investigate the mechanisms by which chicken noodle soup increases plasma osmolality independently of plasma sodium concentrations.

Cardiovascular control, temperature regulation, and physical performance were not affected despite improved fluid balance during exercise with chicken noodle soup. As stated previously, exercise was conducted in a thermoneutral environment where sweat losses and

voluntary dehydration were minimal. Significant decrements in cardiovascular control and temperature regulation occur when access to fluids are restricted and water losses in either sweat or urine are high (12,13,15,16). Based on this information, we believe that if this study were conducted in a hot environment where greater water losses in sweat occur, the additional water intake would serve to preserve cardiovascular function and temperature regulation compared with the inadequate water intake observed in WATER.

In conclusion, 355ml of chicken noodle soup 45 min before the onset of exercise improves fluid balance by persistently increasing water intake and percent water retention throughout 90 min of steady state exercise at 55%  $\text{VO}_{2\text{peak}}$ . The practical implication of this study is that chicken noodle soup before exercise reverses normal voluntary dehydration associated with endurance exercise by maintaining normal water intake after preexercise hyperhydration. The improved fluid balance occurred without the inconvenience of carrying fluids other than water while cycling. Future research should investigate whether sodium inclusion in a preexercise hydration beverage is solely responsible for the observed increase in plasma osmolality and whether increased plasma osmolality causes the improved fluid balance during exercise after chicken noodle soup ingestion.

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## Tables and Figures

**Table 1.** *Participant characteristics before maximal oxygen uptake test.*

	n	Age (yrs)	Weight (kg)	Height (cm)	VO <sub>2peak</sub> (ml/kg·min)
All	20	24 ± 3	68.8 ± 11.9	174.4 ± 9.3	51 ± 10
Men	10	24 ± 3	77.5 ± 9.3*	181.6 ± 6.2*	56 ± 9*
Women	10	23 ± 3	60.1 ± 6.8	167.3 ± 5.5	47 ± 8

All values are means ± SD. \* different than women (p < 0.05)

**Table 2.** *Beverage Composition*

	WATER	CE	CNS
Osmolality, (mosmol/kg)	6.5	382.5	283.3
[Na <sup>+</sup> ], mmol/l	3.1	16.0	166.9
[K <sup>+</sup> ], mmol/l	0.0	3.3	6.9
[Ca <sup>2+</sup> ], mmol/l	0.0	3.7	2.9
Total CHO, g/l	0.0	64.7	46.5
Simple Sugar, g/l	0.0	51.3	1.5
Total Fat, g/l	0.0	0.0	7.0
Total Protein, g/l	0.0	0.0	15.0

Osmolality of CNS determined on liquid fraction. Electrolyte and nutrient concentrations for CNS determined by homogenation. WATER, commercially available bottled water; CE, commercially available carbohydrate/electrolyte solution; CNS, chicken noodle soup; [Na<sup>+</sup>], [K<sup>+</sup>], and [Ca<sup>2+</sup>]; sodium, potassium, and calcium concentration; CHO, carbohydrate.

**Table 3.** *Drinking behavior during 90 min of exercise and subsequent physical performance task.*

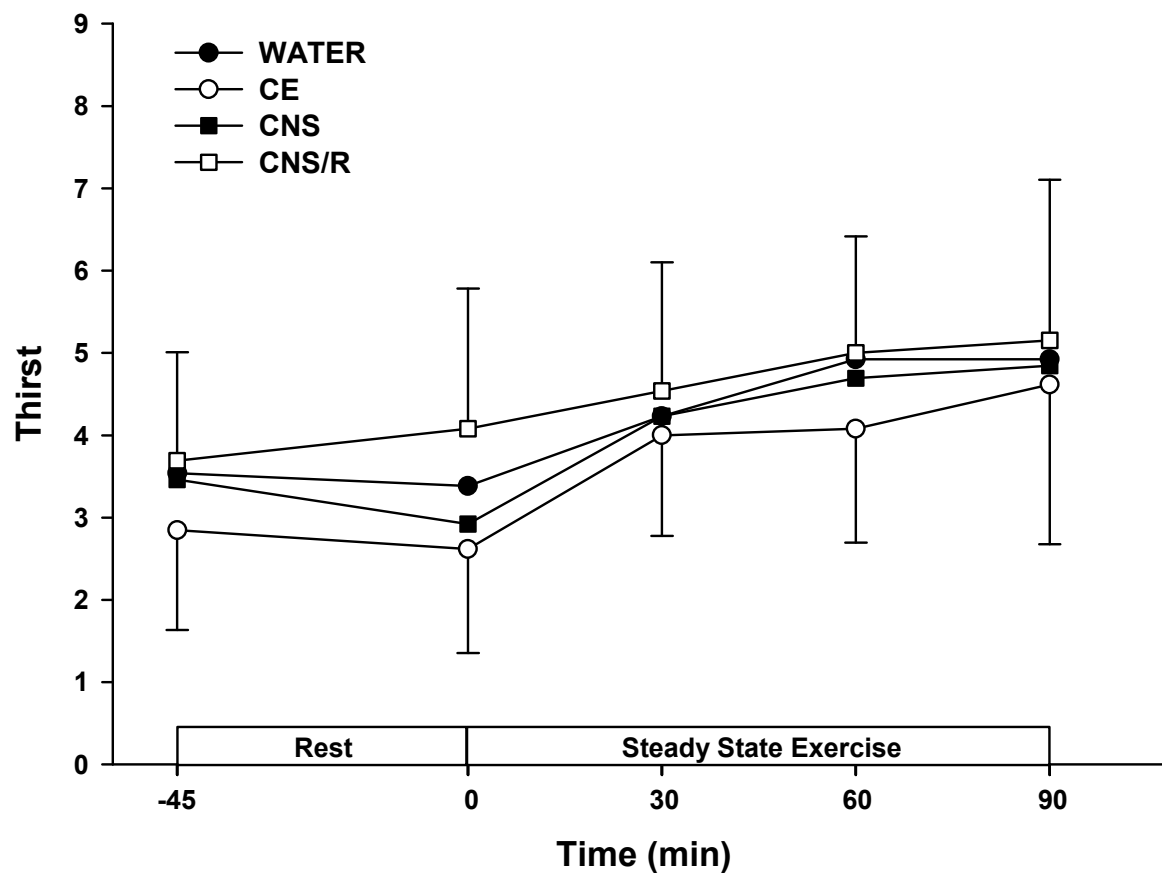
	WATER	CE	CNS	CNS/R
<b>Total Water Intake (g)</b>	<b>862 ± 541</b>	<b>1065 ± 657*</b>	<b>1214 ± 589*</b>	<b>1055 ± 663*</b>
- Metabolic Phase	594 ± 391	669 ± 486	801 ± 415	668 ± 486
- Physical Performance Task <sup>#</sup>	281 ± 214	400 ± 232	417 ± 303	390 ± 233
<b>Rate of Water Intake (g/min)</b>	<b>6.9 ± 4.2</b>	<b>8.8 ± 5.4*</b>	<b>9.8 ± 4.5*</b>	<b>8.6 ± 5.2*</b>
- Metabolic Phase	6.5 ± 4.2	7.4 ± 5.4	8.9 ± 4.6	7.4 ± 5.4
- Physical Performance Task <sup>#</sup>	9.4 ± 6.5 <sup>b1</sup>	15.0 ± 8.1 <sup>a1</sup>	14.0 ± 8.1 <sup>a1</sup>	14.0 ± 7.5 <sup>a1</sup>
<b>Volume per Drink (g/drink)</b>	<b>92 ± 45</b>	<b>103 ± 41</b>	<b>109 ± 51*</b>	<b>103 ± 41</b>
- Metabolic Phase	91 ± 45	99 ± 49	107 ± 59	98 ± 49
- Physical Performance Task	95 ± 63	100 ± 45	104 ± 52	101 ± 44
<b>Time between Drinks (min)</b>	<b>15.9 ± 8.5</b>	<b>14.3 ± 6.1</b>	<b>11.9 ± 4.1*</b>	<b>14.6 ± 6.2</b>
- Metabolic Phase	17.2 ± 6.3	18.1 ± 8.0	14.6 ± 7.0	18.1 ± 8.0
- Physical Performance Task <sup>#</sup>	9.4 ± 5.6	8.3 ± 5.4	7.9 ± 4.1	8.8 ± 5.4

All values are means ± SD. Dissimilar letters are different between trials within a phase, <sup>1</sup> is different between phases within a trial, \* different than WATER for a main trial effect, and <sup>#</sup> different than the metabolic phase for main time effect ( $p < 0.05$ ).

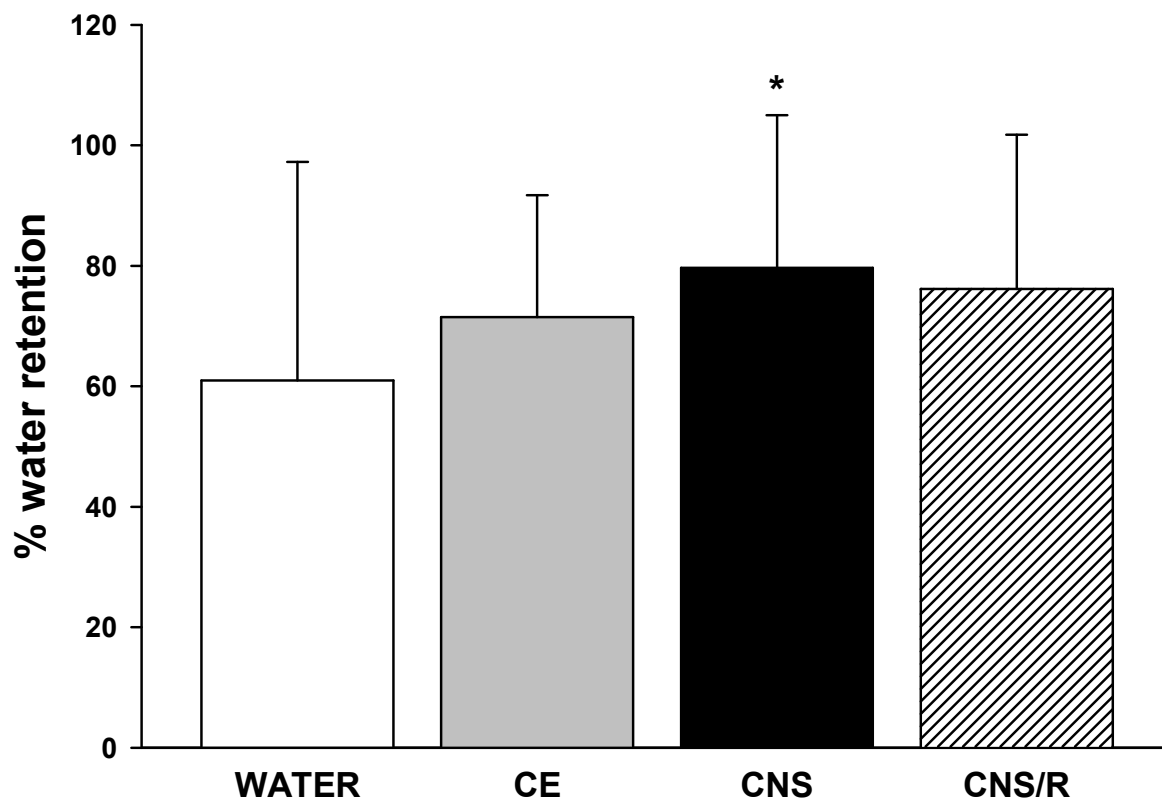
**Table 4.** *Urine measurements after completion of the physical performance task.*

	WATER	CE	CNS	CNS/R
<b>Total Urine Output (ml)</b>	<b>250 ± 221</b>	<b>225 ± 153</b>	<b>190 ± 178</b>	<b>165 ± 117</b>
- Specific Gravity	1.014 ± 0.006	1.014 ± 0.007	1.018 ± 0.007 <sup>+</sup> *	1.019 ± 0.005 <sup>+</sup> *
- Osmolality (mOsm/kg)	521 ± 226	520 ± 245	691 ± 241 <sup>+</sup> *	740 ± 195 <sup>+</sup> *
- Sodium Output (mmol/l)	83 ± 44	68 ± 43	110 ± 51 <sup>+</sup> *	127 ± 45 <sup>+</sup> *
- Potassium Output (mmol/l)	71 ± 44	57 ± 35	87 ± 36 <sup>+</sup>	95 ± 37 <sup>+</sup> *

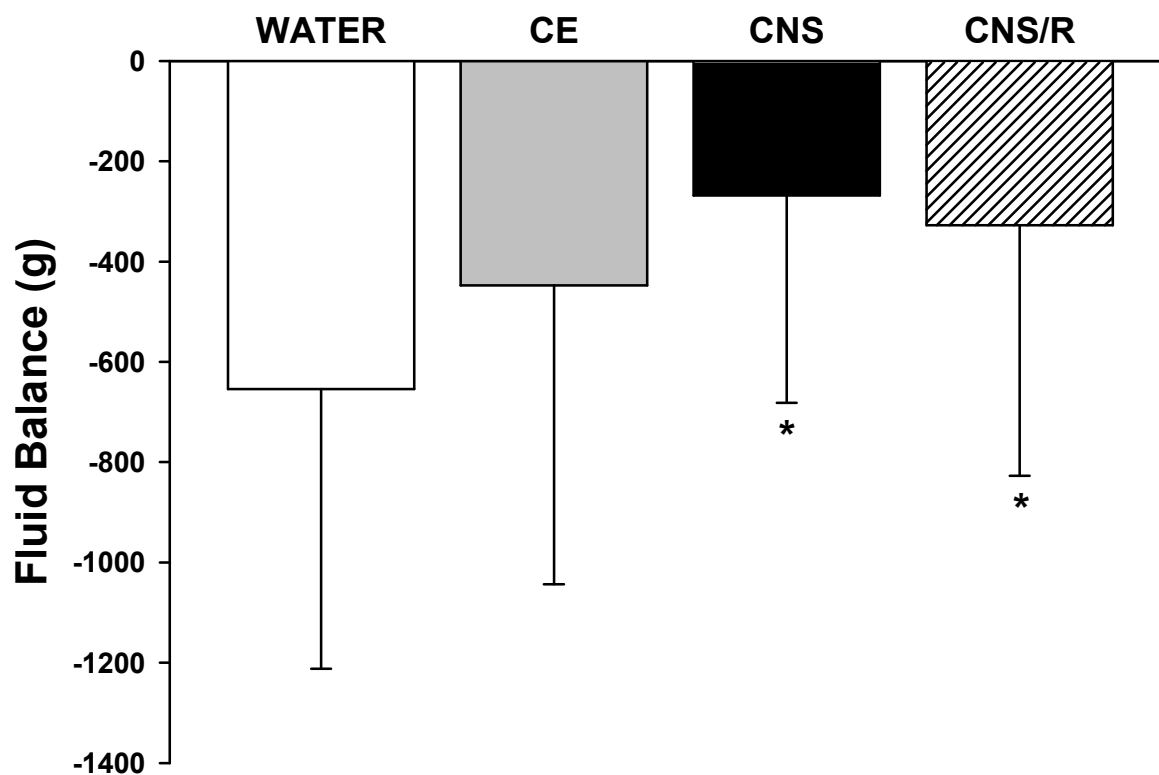
All data are means ± SD. \* different than WATER and <sup>+</sup> different than CE (p < 0.05).



**Figure 1.** Thirst responses during rest and 90 min of steady state exercise at 55%  $\text{VO}_{2\text{peak}}$  (means  $\pm$  SD;  $n = 13$ ). No effect of time, trial, or time by trial exists. For all graphs, -45 (Pre-I), 0 (Pre-Ex), 30 (EX30), 60 (EX60), and 90 (EX90) represent the time relative to the start of steady state exercise.

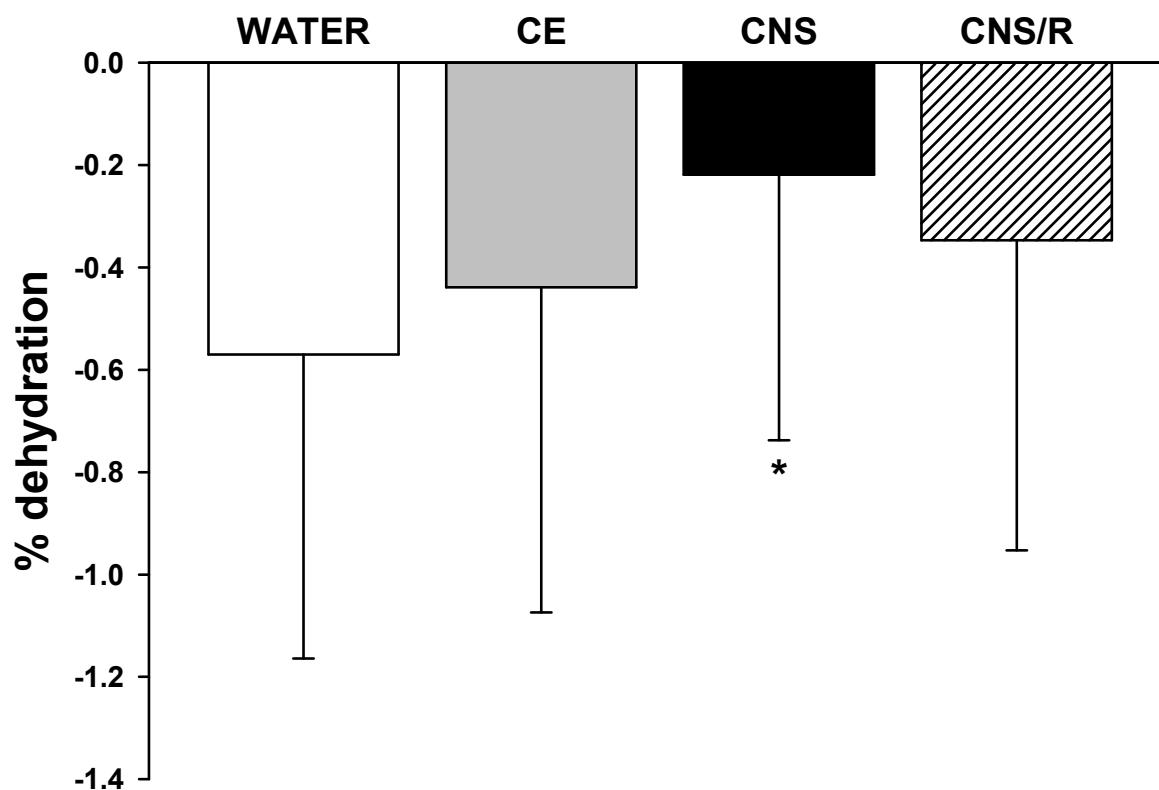


**Figure 2.** Percent water retained after 90 min of exercise at 55%  $\text{VO}_{2\text{peak}}$  and subsequent physical performance task (means  $\pm$  SD). An effect of trial exists ( $p = 0.05$ ) with \* indicating greater percent water retention compared with WATER.



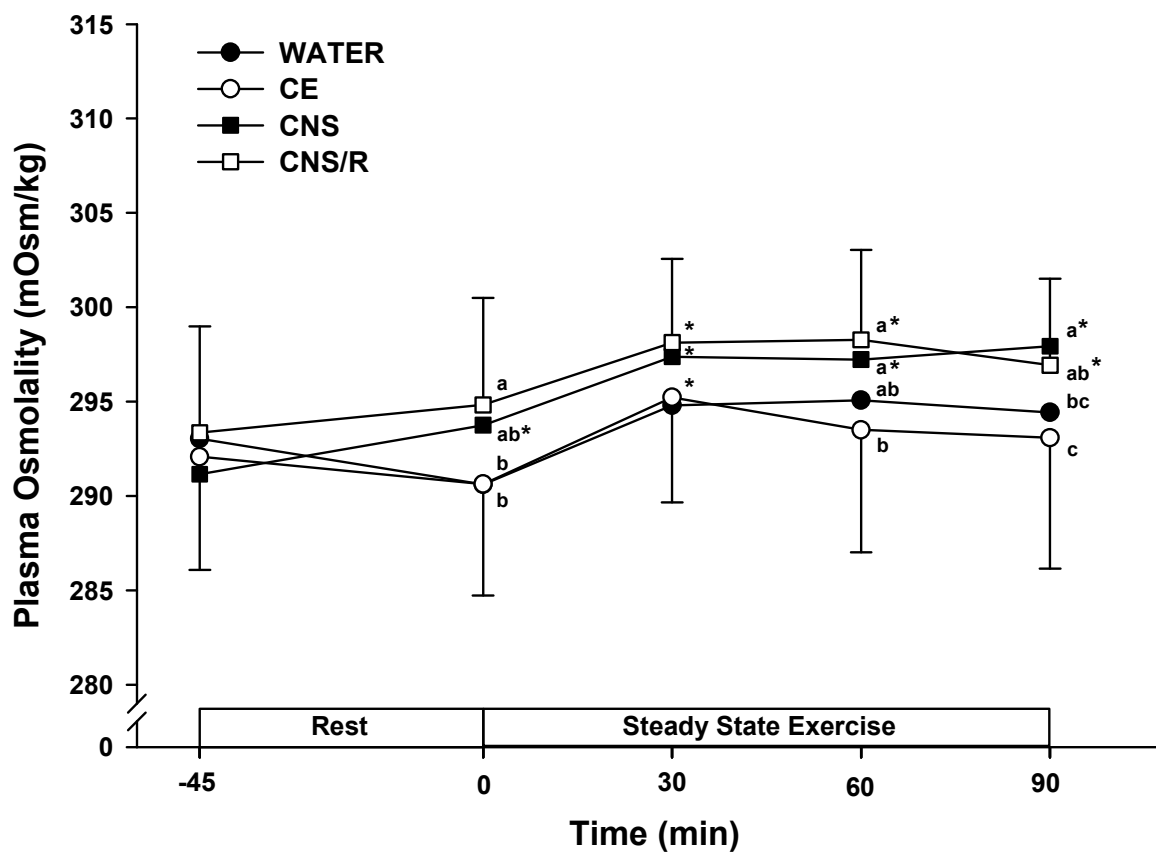
**Figure 3.** Fluid balance after 90 min of steady state exercise at 55%  $\text{VO}_{2\text{peak}}$  (means  $\pm$  SD).

An effect of trial exists ( $p = 0.001$ ) with \* indicating greater fluid balance compared with WATER.

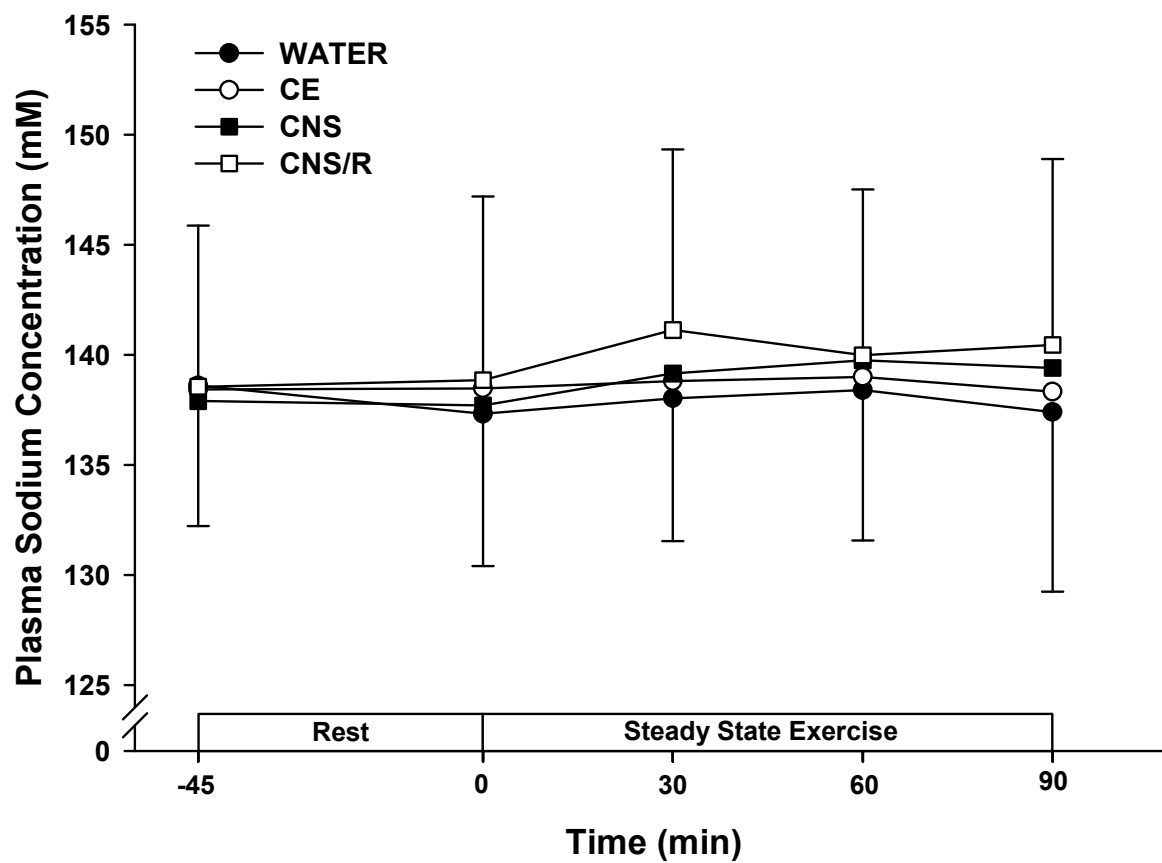


**Figure 4.** Percent dehydration after 90 min of steady state exercise at 55%  $\text{VO}_{2\text{peak}}$  (means  $\pm$  SD). An effect of trial exists ( $p = 0.02$ ) with \* indicating lower percent dehydration compared with WATER.

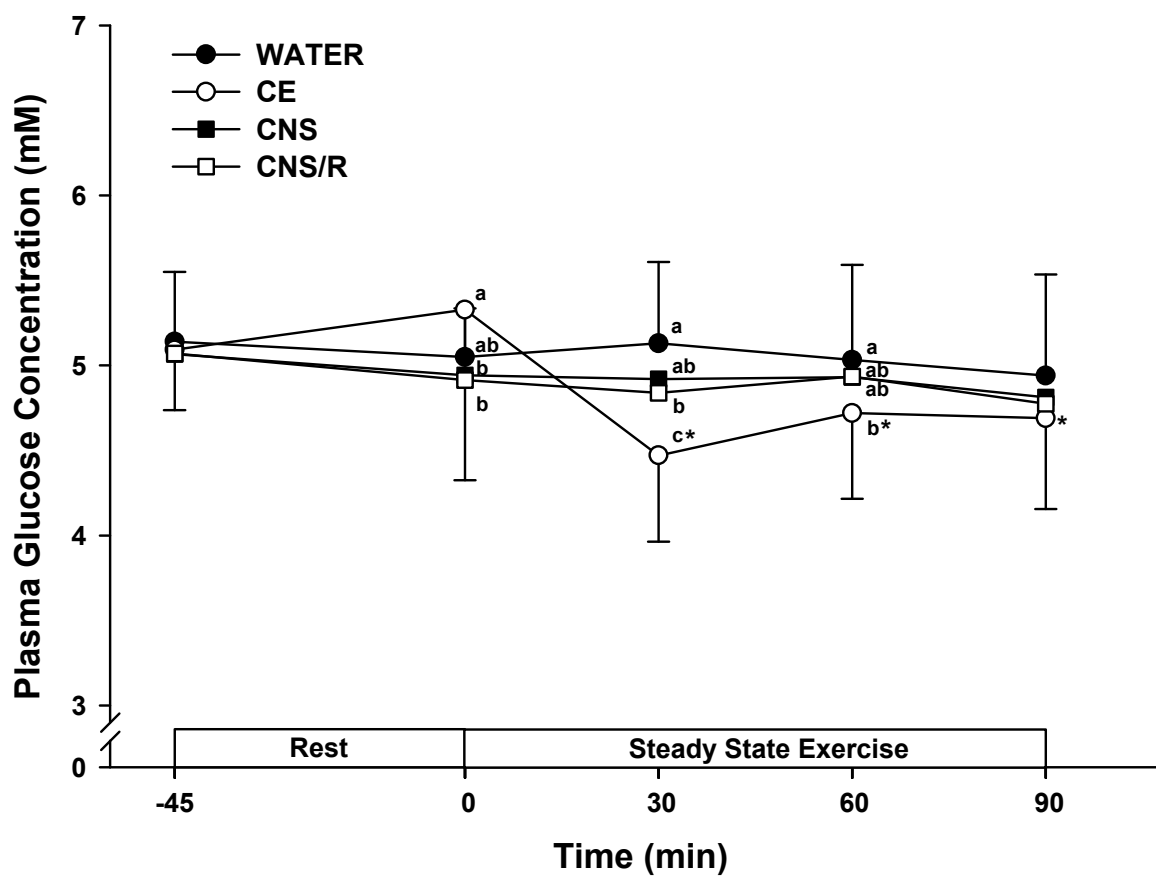




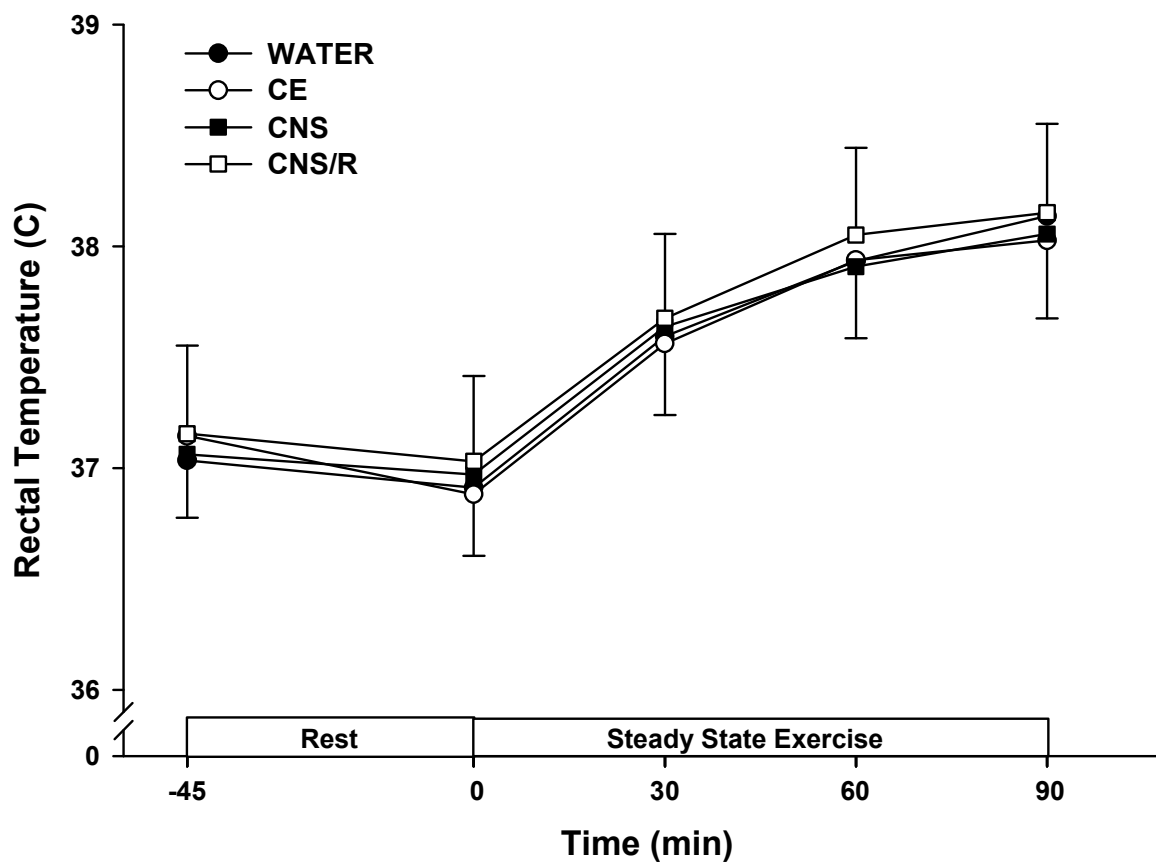
**Figure 5.** Plasma osmolality responses during rest and 90 min of steady state exercise at 55%  $\text{VO}_{2\text{peak}}$  (means  $\pm$  SD). Effects of time ( $p < 0.001$ ), trial ( $p = 0.003$ ), and time by trial interaction ( $p < 0.001$ ) exist. Dissimilar letters are different within a time point and \* is different from -45 (Pre-I).



**Figure 6.** Plasma sodium responses during rest and 90 min of steady state exercise at 55%  $\text{VO}_{2\text{peak}}$  (means  $\pm$  SD). No effect time, trial, or time by trial interaction exists.



**Figure 7.** Plasma glucose responses during rest and 90 min of steady state exercise at 55%  $\text{VO}_{2\text{peak}}$  (means  $\pm$  SD). Effects of time ( $p < 0.001$ ) and time by trial interaction ( $p < 0.001$ ) exist. Dissimilar letters are different within a time point, \* is different from -45 (Pre-I).



**Figure 8.** Rectal temperature responses during rest and 90 min of steady state exercise at 55%  $\text{VO}_{2\text{peak}}$  (means  $\pm$  SD). An effect of time exists ( $p < 0.001$ ) due to a rise in rectal temperature during exercise in all trials compared with rest.

## CHAPTER 4. EFFECT OF ELECTROLYTE-CONTAINING BEVERAGES ON HYDRATION

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### Abstract

Electrolyte beverages ingested before exercise augment fluid balance by increasing *ad libitum* water intake and reducing urine volume during exercise. Whether sodium or other macronutrients are responsible for improvements in fluid balance is equivocal. To determine the effect of sodium on hydration at rest, 10 healthy, young males ingested 355 ml of one of three experimental beverages: water (WATER), water with 1360 mg sodium (SW), or chicken noodle soup (1360 mg Na<sup>+</sup>; CNS). Blood samples were drawn before beverage ingestion and every 5 min for the first 45 min and 60, 80, 100 and 120 min after ingestion of the beverages. Rating of perceived thirst was also collected at these times. A urine sample was collected before beverage ingestion and total urine volumes were collected at 45 and 120 min after ingestion of the experimental beverage. Plasma osmolality increased rapidly (15 min) in CNS and more slowly in SW (60 min) compared with baseline values ( $p < 0.05$ ). The increases in plasma osmolality were independent of plasma sodium concentration. Percent plasma volume was higher throughout rest in CNS compared with WATER. Urine output was greater in WATER from 45 to 120 min compared with SW and CNS. Urine sodium, osmolality, and specific gravity were greater in the last 75 min after CNS and SW compared with WATER. Perceived thirst was similar in all trials (interaction  $p = 0.5$ ).

Chicken noodle soup ingestion results in a rapid increase in plasma osmolality that is independent of plasma sodium concentration. The increased plasma osmolality may have been responsible for the reduction in urine output. Salt water intake caused a slower increase in plasma osmolality, but similar reductions in urine output. Beverage sodium content causes an increase in plasma osmolality and decrease in urine output, but plasma osmolality increases more rapidly with the inclusion of other macronutrients and electrolytes.

## **Introduction**

Ingestion of beverages containing a mixture of macronutrients and electrolytes before exercise, chicken noodle soup, results in augmented fluid balance during subsequent exercise due to a persistent increase in *ad libitum* water intake and improved water retention (N. M. Johannsen, unpublished observations). In this study, we concluded that increased plasma osmolality after ingestion of chicken noodle soup was responsible for greater *ad libitum* and water retention and that the increase in plasma osmolality was independent of plasma sodium concentration. However, because chicken noodle soup not only contains significant sodium (167 mM), but also many other macronutrients and electrolytes, we were unable to determine whether sodium truly had no effect on plasma osmolality or whether the increase was due to a combination of soup constituents.

Many studies have investigated the effects of electrolytes and macronutrients on gastric emptying (1-6) and intestinal absorption (7-9) and subsequent changes in plasma osmolality (10-14). These studies suggest that the major determinant of gastric emptying is caloric density. Other research implicates the total volume of the beverage or beverage osmolality (1,15) in the rate of gastric emptying, but Hunt and Stubbs (3) suggest that gastric

emptying is independent of volume if the volume is between 300 and 500 ml. While delayed gastric emptying may slow effective absorption and assimilation of food or liquids, expedited intestinal absorption as a result of nutrient addition to experimental beverages may effectively lower the overall time of absorption. Once a hypotonic solution reaches the intestine, significant secretion of solutes occurs and that addition of carbohydrate and electrolytes to these beverages reduces intestinal secretion and augments fluid uptake provided the osmolality is near isotonic and carbohydrate content is no greater than ~ 6% (8,9,16-18). Although the chicken noodle soup used in our previous study was given in a 355 ml bolus and contains < 3% carbohydrate, it also contains fat and protein which may slow gastric emptying significantly (5,6). Whether the additional macronutrients and electrolytes contained in the soup speeds or slows changes in plasma constituents compared with water containing a similar amount of sodium chloride is equivocal.

This study was conducted to determine how rapidly chicken noodle soup increases plasma osmolality and whether plasma sodium concentration is responsible for these effects. We also investigated whether beverages containing an equal amount of sodium elicit similar increase plasma osmolality without subsequent changes in plasma sodium concentration. Secondly, we investigated whether a single bolus of electrolyte containing beverages affects urine production and perceived thirst. We hypothesized that the ingestion of chicken noodle soup would expedite increased plasma osmolality compared with both water and salt water ingestion, but the increase in plasma osmolality would be independent of plasma sodium concentration. We also hypothesized that because the increase in plasma osmolality

would occur rapidly after chicken noodle soup, urine volume would be reduced and thirst would be greater for up to 2 h.

## **Methods**

### *Participant Characteristics*

Ten healthy men ( $26.9 \pm 4.1$  y,  $182.9 \pm 7.5$  cm,  $85.0 \pm 11.4$  kg) volunteered to participate in this study. Prior to any testing, participants completed a medical history questionnaire that was reviewed and approved by the primary investigators. The study was approved by the Iowa State University Institutional Review Board and all participants gave informed, written consent.

### *Experimental Protocol*

Volunteers participated in three trials separated by at least 7 d. Prior to all of the trials, the participants fasted for at least 10 h, refrained from strenuous exercise for at least 16 h, and drank at least 1 extra liter of water to ensure proper hydration. Before the first trial, participants kept a 1-d diet diary that was replicated prior to subsequent trials. The participants entered the laboratory and immediately provided a urine sample. After returning to the laboratory, the participants had a 2 in flexible teflon catheter inserted into an antecubital vein and rested in a seated position for 15 min. A blood sample was drawn (8 ml) after the rest period and the participants ingested 355 ml of one of the three experimental beverages issued in a randomized, counterbalanced, crossover design; water (WATER); water plus 3460 mg sodium chloride (Diamond Crystal® Kosher Salt; SW), or chicken noodle soup (CNS). Beverage compositions are located in Table 1. The amount of sodium chloride added to SW was chosen so that SW and CNS contained similar concentrations of



sodium (1360 mg or 166.8 mM). In order to replicate the administration of similar beverages given in past studies (1, N. M. Johannsen, unpublished observations), WATER was given at 68-70°F (~20°C) and SW and CNS were heated to ~120°F (~50°C). Blood samples were drawn every 5 min for the first 45 min and 60, 80, 100, and 120 min after ingestion of the experimental beverage. Five ml of blood were drawn at each of the time points except for baseline, 45 min, and 120 min in which 8 ml was drawn for the determination of plasma volume change. All blood samples were immediately placed into tubes containing lithium heparin (BD Biosciences, San Jose, CA), analyzed for hematocrit (Hct) and hemoglobin (Hb) concentration, centrifuged at 400 x g, and stored at -20 °C until subsequent analyses could be run. After each blood draw, the catheter was kept patent with 3 ml of sterile saline. Total urine volumes were collected at 45 min and 120 min after ingestion of the experimental beverage. Ratings of perceived thirst were recorded immediately after every blood sample. Perceived thirst was indicated using an analogue scale by a vertical line drawn across a 10 cm reference line. The distance measured from the origin (0 cm) was recorded as perceived thirst. The participants remained seated and were not allowed additional food or drink throughout the entire trial.

### *Biochemical Analyses*

Baseline, 45 min, and 120 min blood samples were analyzed in triplicate for Hct by microcapillary centrifugation and Hb using the cyanmethemoglobin spectrophotometric (Stanbio, Boerne, TX) assay. All Hct values were corrected for trapped plasma volume between red blood cells (0.96) and venous-to-total body Hct ratio (0.91; 19). Percent plasma volume change was calculated using the equations of Dill and Costill (20) with baseline

measurements as a reference. Plasma and urinary osmolalities were measured by freezing point depression (Westcor, Inc., Logan, Utah) and sodium concentrations by digital flame photometry (Cole-Parmer, Chicago, Ill.). Total urine volume was collected 45 and 120 min after ingestion of the experimental beverage and urine was additionally analyzed for specific gravity by spectral refractometry (Leica Microsystems, Inc., New York, NY) at baseline, 45 min, and 120 min. All plasma and urine measurements were performed in duplicate.

### *Statistical Analyses*

All statistics were performed with Sigma Stat statistical software (Systat Software, Inc., San Jose, CA). Pre-trial variables were analyzed using one-way repeated measures analyses of variance (ANOVA) in order to assure proper dietary control. Total urine and sodium output were also analyzed using one-way repeated measures ANOVAs. Urine (volume, sodium, specific gravity, and osmolality) and plasma variables (% plasma volume change, sodium, and osmolality) and perceived thirst were subjected to two-way repeated measures ANOVA's. Significant trial, time, and/or time by trial interaction effects were evaluated further using Holm-Sidak post hoc analyses where appropriate. Interior standard deviation bars have been removed to prevent obscuring internal data points. Data are reported as means  $\pm$  SD and statistical differences were declared if  $p < 0.05$ .

### **Results**

Baseline plasma sodium and osmolality were similar at the start of all trials. All urinary indices of hydration status were similar prior to ingestion of the experimental beverage. Ratings of perceived thirst were also similar at baseline.

Plasma osmolality was higher 5 min after CNS ingestion compared with WATER and after 15 min compared with baseline values ( $280.1 \pm 3.6$  vs.  $282.9 \pm 4.2$ , respectively). The increase in plasma osmolality persisted through at least 100 min of rest (Figure 1). Although CNS and SW contained similar amounts of sodium, plasma osmolality did not change until 60 min in SW. The change in osmolality observed in CNS was slowed significantly in SW even though the trials contained similar amounts of sodium. A rise in osmolality was observed after 60 min in the SW trial compared with baseline SW values. Plasma osmolality in WATER was unchanged throughout the entire 120 min of rest. Plasma sodium concentrations did not change over time in any trial (Figure 2). Plasma volume was higher in CNS after 45 min and remained higher throughout rest compared with WATER (Figure 3). Plasma volume in the SW trial was similar to both the CNS and WATER trials.

Total urine output was similar ( $p = 0.13$ ) after WATER ( $290 \pm 183$  ml), CNS ( $189 \pm 211$  ml), and SW ( $178 \pm 101$  ml) ingestion. However, urine output increased during the last 75 min of rest after WATER ingestion compared to CNS and SW (Figure 4). Urine specific gravity and osmolality were lower at 120 min of rest after WATER ingestion compared with both CNS and SW (interaction  $p = 0.004$  and  $< 0.001$ , respectively). Urinary sodium concentrations were higher at 120 min after CNS ingestion and lower in WATER at 120 min compared with baseline and 45 min (trial by time effect  $p < 0.001$ ; Table 2). Urine sodium concentration was greater in SW at 45 min and in SW and CNS at 120 min compared with WATER. Because of the large changes in urine sodium concentrations and relatively smaller changes in urine output, sodium output was greater in the last 75 min of rest in CNS and SW compared with the first 45 min (trial by time interaction  $p = 0.006$ ; Figure 5).

Perceived thirst was similar in all trials (interaction  $p = 0.5$ ; Figure 6). However, an effect of time ( $p = 0.005$ ) exists due to a prolonged suppression of thirst after ingestion of all beverages.

## **Discussion**

Initial research investigating chicken noodle soup as a preexercise hyperhydration beverage indicates a substantial increase in plasma osmolality within 45 min (N. M. Johannsen, unpublished observations). The results of this experiment corroborate those in our previous research and demonstrate that the increase in plasma osmolality is very rapid occurring within 15 min compared with baseline measurements (Figure 1). In support of our hypothesis and similar to the previous experiment, the increase in plasma osmolality after CNS appear to be independent of plasma sodium responses (figure 2). The time course for the increased plasma osmolality is much slower after ingestion of the sodium chloride showing no effect until 60 min of rest. Similar to CNS, the increase in plasma osmolality appears to be independent of plasma sodium content. Ingestion of bottled water had little to no effect on plasma osmolality and plasma sodium concentration except for a slight, insignificant depression in both measurements approximately 25 – 30 min after the start of the experiment. Interestingly, the increased plasma osmolality that occurred rapidly with chicken noodle soup and more slowly with salt water compared with bottled water ingestion persisted to some degree throughout the remainder of the 2 h of rest.

We did not directly measure gastric emptying or intestinal absorption in this study, but we can interpret our plasma and urine results obtained in this study based on past literature. The addition of macronutrients to the experimental beverage slows the rate of

gastric emptying but concurrently increases intestinal absorption. Although the rate of gastric emptying is delayed with beverages containing carbohydrates, fats, and proteins, the rate of gastric emptying seems to be more related to the caloric density of the food (1-6,8). The calculated caloric density of chicken noodle soup is approximately 0.31 kcal/ml. According to a review of 33 human studies by Hunt and Stubbs (3) the time to empty half of the beverage from the stomach ( $t_{0.5}$ ) should be about 20 min (equation 2; p 216). Because both the water and chicken noodle soup have relatively low caloric densities, a drastic slowing of gastric emptying can not explain the rapid increase in plasma osmolality that occurs in chicken noodle soup that does not occur in the salt water (caloric density = 0). The predicted gastric emptying  $t_{0.5}$  of chicken noodle soup indicates that the increase in plasma osmolality is occurring before half of the contents are emptied from the stomach. In this same review, the authors state that volumes of 350 to 500 ml do not slow gastric emptying. However, because beverage volume in each trial was held constant at 355 ml, beverage volume can not explain gastric emptying rates or the resultant disparities plasma indices.

While gastric emptying rate does not seem to explain the rate of plasma osmolality increase, at least two mechanisms within the intestinal lumen may be responsible: rapid movement of solutes and water from the intestinal lumen to the plasma or secretion of hypotonic fluid out to the intestinal lumen. Several studies have indicated that hypertonic solutions containing carbohydrates, even mildly hypertonic chicken noodle soup, cause an increase in the rate of water and solute flux across the proximal intestinal segments equal to that of water or water plus electrolytes (8,17,18;21). The inward flow of solutes, initially carbohydrate and later sodium (17), could result in an increase in plasma osmolality.

Negative water flux, water flow out of the intestinal mucosa into the lumen, after hypertonic beverage ingestion may also be responsible an increase in plasma osmolality, but little evidence exists to support this idea (8,9,22). The combined effects of fluid outflow into the intestine and uptake of glucose and electrolytes into the plasma may explain the increase in plasma osmolality observed in the chicken noodle soup trial. These results may also explain why the less hypertonic salt water trial, containing no carbohydrates, slows the rate of increase in plasma osmolality. However, we are currently unable to explain why the increase in plasma osmolality is independent of plasma sodium concentrations, but these differences may be related to a combination of the other macronutrients and electrolytes contained in the soup and the effective tonicity of soup after complete digestion. Future research should include measurements of gastric emptying and intestinal absorption of water and solutes to determine how chicken noodle soup rapidly causes the rapid increase in plasma osmolality without influencing plasma sodium concentrations.

The persistent increase in plasma volume suggests an increase in intravascular fluid before 45 min of rest in the chicken noodle soup trial (trial effect:  $CNS > WATER$ ). We can only speculate as to the mechanism(s) responsible for the augmented plasma volume after chicken noodle soup ingestion. This increase in plasma volume may be related to the absorption of the experimental beverage and/or fluid displacement into the plasma from surrounding extracellular reserves caused by the increase in plasma osmolality. However, other researchers have failed to show differences in plasma volume related to either the composition and tonicity of the beverages (8,9,16,17,22). Interestingly, we observed a reduced plasma volume 45 min after the ingestion of 355 ml of bottled water which may also

be related to the movement of electrolytes and/or intravascular water between body compartments.

Our second hypothesis was that the increase in plasma osmolality after chicken noodle soup ingestion would reduce urine output and an increase perceived thirst. In the present study, we did observe a reduced urine output in both the chicken noodle soup and salt water trials during the last 75 min of rest. Our results concur with previous studies indicating a reduced urine formation related to plasma osmolality and a concomitant increase in water conserving hormone concentrations (23,24). These studies show that small increases in plasma osmolality result in dramatic increases in plasma renin activity and arginine vasopressin and angiotensin II concentrations. We did not find an increase thirst perception normally associated with the aforementioned systemic water balance regulating mechanisms. Although similar perceived thirst responses in all trials were unexpected, the relative small increase in plasma osmolality and similarity in gut distention (25-28) together with the lack of additional external stimuli to drink such as exercise may explain these results.

The main outcome of this study was that ingestion of chicken noodle soup rapidly increased plasma osmolality without concurrently affecting plasma sodium concentrations. Water containing an equal amount of sodium increased plasma osmolality more slowly than chicken noodle soup, but also did so without influencing plasma sodium concentrations. The augmented plasma osmolality reduced urine output during the last 75 min of rest in both the salt water and chicken noodle soup trials and increased plasma volume after soup ingestion. Future research should investigate the mechanism(s) for the rapid increase in plasma osmolality associated with chicken noodle soup and whether the improved fluid balance

during exercise after soup ingestion is great enough to preserve cardiovascular function and temperature regulation during exercise in the heat.

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## Tables and Figures

**Table 1.** *Beverage Composition*

	WATER	CNS	SW
Osmolality, (mosmol/kg)	6.5	382.5	322.0
[Na <sup>+</sup> ], mmol/l	3.1	166.9	166.8
[K <sup>+</sup> ], mmol/l	0.0	6.9	0.0
[Ca <sup>2+</sup> ], mmol/l	0.0	2.9	0.0
Total CHO, g/l	0.0	46.5	0.0
Simple Sugar, g/l	0.0	1.5	0.0
Total Fat, g/l	0.0	7.0	0.0
Total Protein, g/l	0.0	15.0	0.0

Osmolality of CNS and SW determined on liquid fraction. Electrolyte and nutrient concentrations for CNS determined by homogenation. WATER, commercially available bottled water; CNS, chicken noodle soup; SW, commercially available bottled water + 3.46 g NaCl; [Na<sup>+</sup>], [K<sup>+</sup>], and [Ca<sup>2+</sup>]; sodium, potassium, and calcium concentration; CHO, carbohydrate.

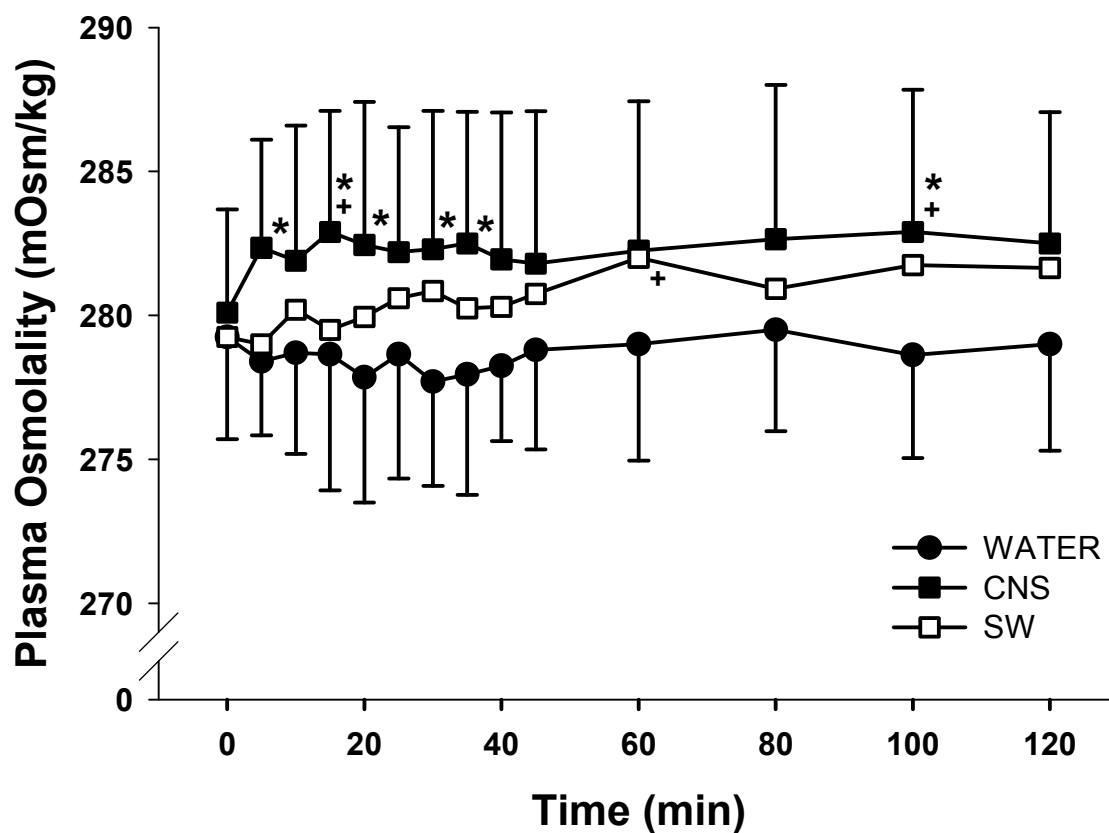
**Table 2.** *Urine measurements at 45 and 120 min of rest after experimental beverage ingestion.*

	WATER	CNS	SW
<b>Specific Gravity</b>			
Baseline	1.020 ± 0.007 <sup>+</sup>	1.019 ± 0.007	1.020 ± 0.007
45 min	1.017 ± 0.009 <sup>+</sup>	1.021 ± 0.007	1.021 ± 0.007
120 min	1.013 ± 0.009	1.020 ± 0.006*	1.017 ± 0.006*
<b>Osmolality (mOsm/kg)</b>			
Baseline	768.1 ± 222.7 <sup>+</sup>	724.4 ± 269.5	741.3 ± 285.6
45 min	655.5 ± 323.8 <sup>+</sup>	805.9 ± 253.5	813.9 ± 257.6
120 min	492.1 ± 327.6	798.3 ± 248.9*	721.3 ± 243.5*
<b>[Na<sup>+</sup>] (mmol/l)</b>			
Baseline	141.6 ± 60.2 <sup>+</sup>	127.7 ± 39.6 <sup>+</sup>	139.9 ± 60.0
45 min	121.6 ± 69.4 <sup>+</sup>	144.9 ± 52.8 <sup>+</sup>	162.4 ± 64.2*
120 min	85.8 ± 53.2	177.7 ± 57.5*	164.5 ± 60.5*

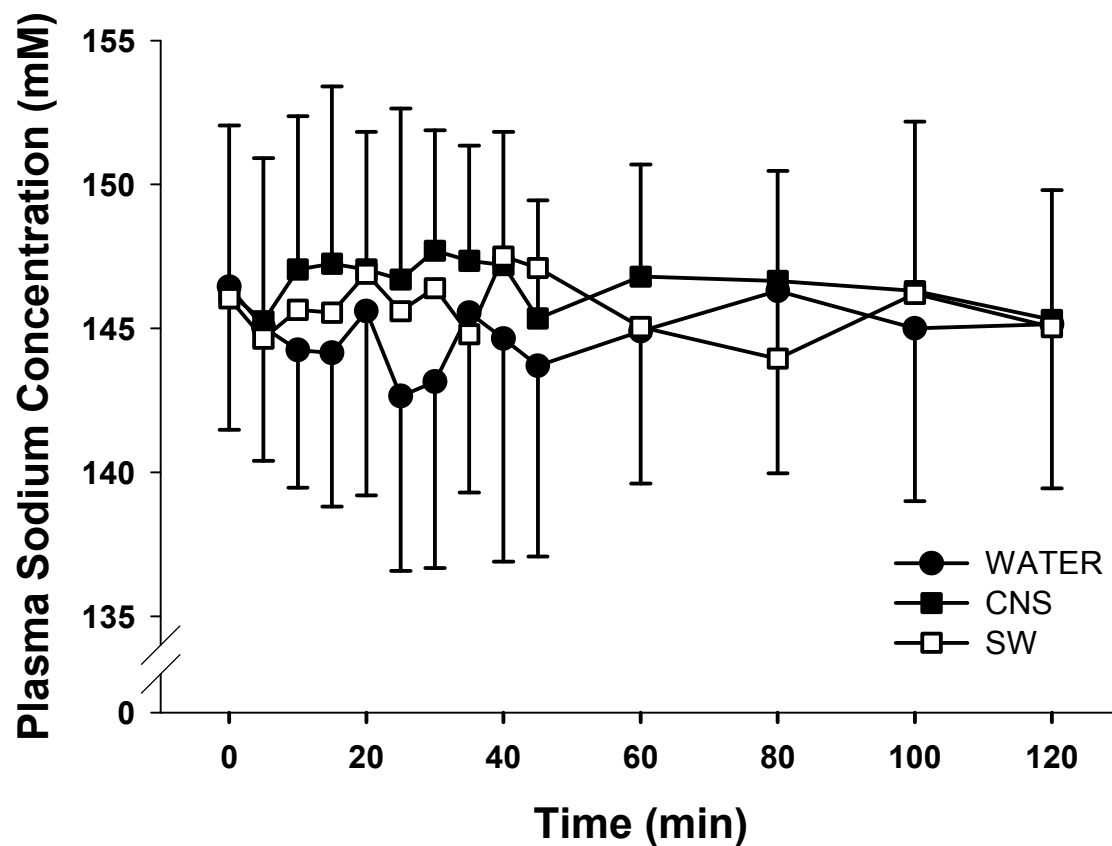
All data are means ± SD. \* different than WATER at a given time point and <sup>+</sup> different than

120 min of rest within a trial ( $p < 0.05$ ). WATER, commercially available bottled water;

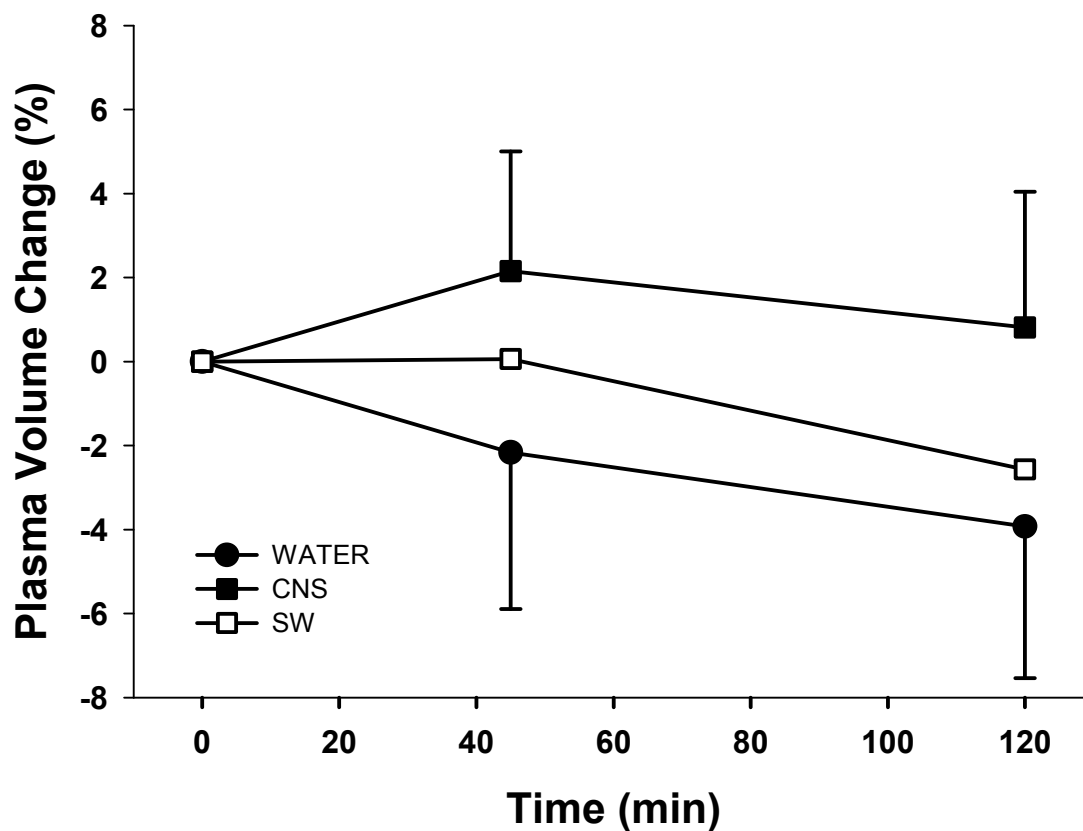
CNS, chicken noodle soup; SW, commercially available bottled water + 3.46 g NaCl.



**Figure 1.** Plasma osmolality response during 2 h rest after ingesting either 355 ml of commercially available bottled water (WATER), chicken noodle soup (CNS), or water containing equal sodium content to CNS (SW; means  $\pm$  SD). Effects of time ( $p = 0.005$ ) and trial by time interaction ( $p = 0.03$ ) exist. <sup>+</sup> different than before beverage ingestion and <sup>\*</sup> different than WATER at a given time point.

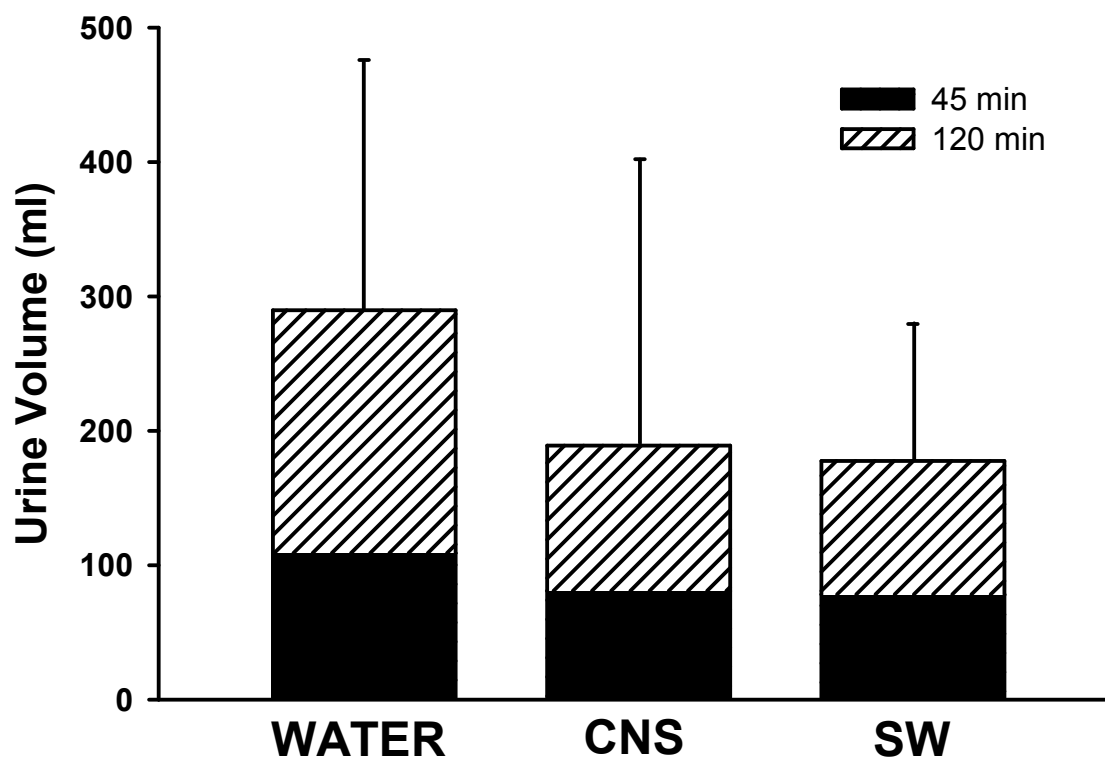


**Figure 2.** Plasma sodium response during 2 h rest after ingesting either 355 ml of commercially available bottled water (WATER), chicken noodle soup (CNS), or water containing equal sodium content to CNS (SW; means  $\pm$  SD). No effect of trial ( $p = 0.5$ ), time ( $p = 0.8$ ), or trial by time interaction ( $p = 0.7$ ) exists.



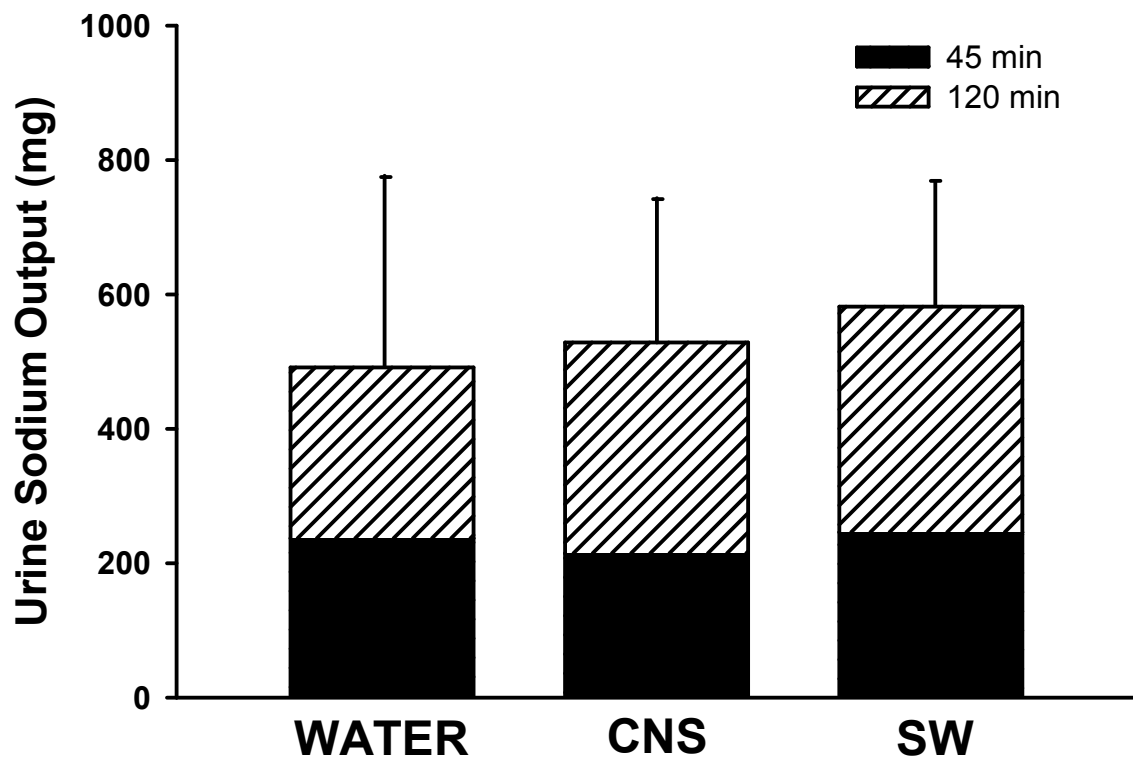
**Figure 3.** Percent plasma volume response during 2 h rest after ingesting either 355 ml of commercially available bottled water (WATER), chicken noodle soup (CNS), or water containing equal sodium content to CNS (SW; means  $\pm$  SD). Effects of trial ( $p = 0.04$ ) and time ( $p = 0.005$ ) exist. Plasma volume was greater in CNS than WATER and 45 min is greater than 120 min of rest.



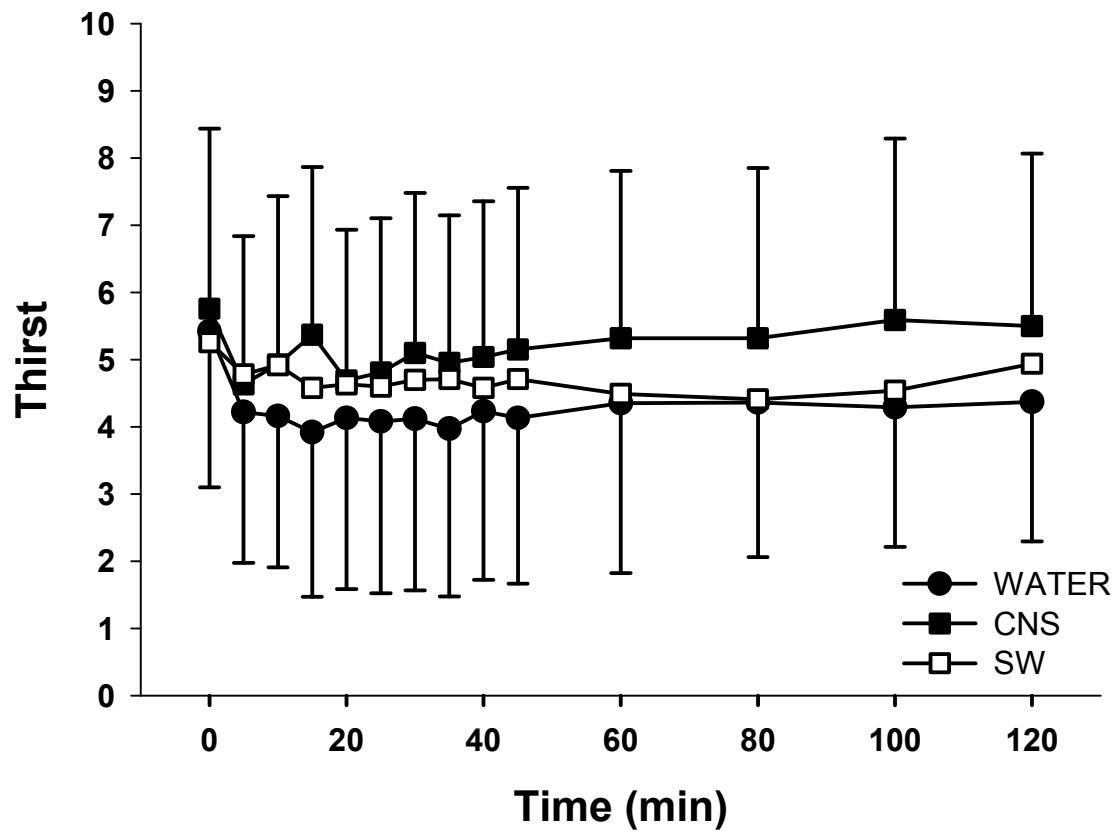


**Figure 4.** Urine volume during 2 h rest broken down into time increments (means  $\pm$  SD).

Standard deviation bars are for total urine volume. Effects of time ( $p = 0.005$ ) and trial by time interaction ( $p = 0.04$ ) exist due to an increase in urine production during the last 75 min of rest after WATER (120 min) compared with the initial 45 min and last 75 min in CNS and SW (120 min). Total urine production was similar between trials ( $p = 0.13$ ).



**Figure 5.** Urine sodium output during 2 h rest broken down into time increments (means  $\pm$  SD). Standard deviation bars are for total sodium output. Effects of time ( $p < 0.001$ ) and trial by time interaction ( $p = 0.006$ ) exist due to an increase in sodium output during the last 75 min of rest after CNS and SW (120 min) compared with the initial 45 min. Total sodium output was similar between trials ( $p = 0.6$ ).



**Figure 6.** Perceived thirst response during 2 h rest after ingesting either 355 ml of commercially available bottled water (WATER), chicken noodle soup (CNS), or water containing equal sodium content to CNS (SW; means  $\pm$  SD). An effect of time ( $p = 0.005$ ) exists due to an immediate suppression of thirst after ingestion of the experimental beverages that lasts for at least 80 min.

## CHAPTER 5. PREEXERCISE BEVERAGE COMPOSITION IMPACT ON HYDRATION AND PERFORMANCE DURING EXERCISE UNDER COMPENSABLE HEAT STRESS

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### Abstract

Chicken noodle soup before exercise improved fluid balance by increasing in *ad libitum* water intake and water retention during 90 min of exercise in a thermoneutral environment. The improved fluid balance did not promote cardiovascular, thermoregulatory, or performance benefits. To determine whether additional body fluid resulting from soup ingestion before exercise improves cardiovascular function, temperature regulation, and physical and cognitive performance, we recruited 9 trained college-aged men ( $25 \pm 3$  y and  $54.2 \pm 5.1$  ml/kg·min; means  $\pm$  SD) to exercise in the heat (WBGT =  $25.7 \pm 0.4^\circ\text{C}$ ) for 90 min at  $\sim 50\%$   $\text{VO}_{2\text{peak}}$ , 45 min after ingesting 355 ml of either commercially available bottled water (WATER) or chicken noodle soup (CNS). Water intake during exercise was allowed *ad libitum* in CNS and WATER. In a third trial (WATER/R), the amount and timing of water ingested was similar to CNS. After steady state exercise, participants ( $n = 8$ ) completed a physical performance task (PPT) consisting of the time to complete 10 min of work at  $90\%$   $\text{VO}_{2\text{peak}}$ . Water was allowed *ad libitum* in all trials during the PPT. Fluid balance was improved in CNS compared with WATER ( $p < 0.05$ ) due to an increase in *ad libitum* water intake during steady state exercise ( $p < 0.01$ ; CNS, WATER/R  $>$  WATER). Water intake during the PPT was lower in WATER/R than CNS and WATER. Total urine

output was similar in all trials, but free water clearance was improved in CNS ( $-0.3 \pm 1.2$  g/min) compared with both WATER and WATER/R ( $0.5 \pm 1.1$  and  $0.6 \pm 1.0$ , resp.;  $p = 0.02$ ). Plasma osmolality and potassium concentrations were similar between trials. Plasma sodium was higher ( $p < 0.02$ ) in CNS compared with WATER/R. Ratings of perceived thirst were higher in both CNS and WATER compared with WATER/R during the last 30 min of exercise. Cardiovascular function, temperature regulation, and physical and cognitive performance were unaffected by beverage intake before exercise or water intake during exercise. Chicken noodle soup promoted fluid balance during exercise in the due to an increase in *ad libitum* water intake. Perceived thirst was directly related to the amount of water ingested during exercise. Chicken noodle soup before exercise may prevent the fall in plasma sodium concentration associated with sweat sodium losses and high rates of water intake during exercise in the heat.

## **Introduction**

Fluid intake during exercise under compensable heat stress, where required energy loss to maintain body temperatures is lower than the energy the environment can absorb, is critical in order to maintain cardiovascular control and body temperature regulation. When fluid intake is inadequate during exercise in the heat, skin blood flow and sweat rates are reduced in order to preserve cardiovascular function resulting in exacerbated heat gain and loss of temperature control (1-6). The resultant gain in body heat has been implicated in fatigue when body temperature reaches  $\sim 40^{\circ}\text{C}$  (7,8). Performance decrements are associated with dehydration as low as 2% loss of body mass and forced water intake, and associated improvements in fluid balance, significantly improves both physical (9-14) and cognitive (15-

17) performance. When voluntary dehydration is prevented by forced water intake equal to water losses in sweat, sweat rate, cardiovascular function, and temperature regulation are improved (1-3,18). However, whether additional voluntary water intake and improved fluid balance during exercise in the heat improves physical and cognitive performance compared with mild dehydration is unknown.

Although preexercise hyperhydration has been implicated in improved temperature regulation during exercise (19,20), simple water hyperhydration has yielded conflicting results (21-23). The addition of glycerol, an active osmotic agent, to the hyperhydration beverage decreases urine output and promotes whole body fluid expansion compared with water hyperhydration (24-26). However, the benefits of glycerol hyperhydration in exercise are debatable with some studies demonstrating significant improvements in temperature regulation and sweat rates (25,27) and others showing no improvements in sweat rates or sweat responsiveness (28-29). We have recently observed that mild preexercise hyperhydration with beverages containing high concentrations of sodium and other macronutrients and electrolytes (355 ml chicken noodle soup) completely abolishes voluntary dehydration by increasing *ad libitum* water intake and water retention compared with a similar level of water hyperhydration (N. M. Johannsen, unpublished observations). However, because the exercise was in a thermoneutral environment ( $WBGT = 16.2 \pm 1.6^{\circ}\text{C}$ ), the differences in sweat rate, cardiovascular control, temperature regulation, and physical performance were negligible.

The purpose of this investigation was to determine whether mild hyperhydration with chicken noodle soup increases water intake and water retention, subsequently improving fluid

balance during exercise under compensable heat compared with water hyperhydration. A second purpose was to determine whether the improvement in fluid balance with chicken noodle soup ingestion before exercise results in enhanced cardiovascular function, temperature regulation, and physical and cognitive performance during exercise in the heat. Finally, we sought to determine whether increased water intake with chicken noodle soup before exercise is solely responsible for the improvements in fluid balance and potential cardiovascular, thermoregulatory, and performance benefits. We hypothesized that chicken noodle soup before exercise under compensable heat stress results in greater *ad libitum* water intake and water retention leading to improved fluid balance compared with water intake before exercise. We also hypothesized that the improvement in fluid balance would enhance cardiovascular function, temperature regulation, and physical and cognitive performance. Further, we hypothesized that when water intake was regulated by time and volume to chicken noodle soup in a second water hyperhydration trial, similar fluid balance, cardiovascular, thermoregulatory, and performance benefits to the chicken noodle soup trial would ensue. However, because we expected greater water intake in the second water trial, we hypothesized that perceived thirst and water retention would be reduced.

## **Methods**

### *Participant Characteristics*

Ten healthy, trained college aged men ( $25 \pm 3$  y,  $75.8 \pm 6.8$  kg,  $174.0 \pm 5.0$  cm,  $54.2 \pm 5.1$  ml/kg·min; means  $\pm$  SD) were recruited for this study. Prior to any physical testing, participants completed a medical history questionnaire that was reviewed and approved by

the primary investigators. The study was approved by the Iowa State University Institutional Review Board and all participants gave informed, written consent.

### *Preliminary Testing*

Before the first trial, participants underwent a graded exercise test (GXT) on a cycle ergometer (Monark Exercise AB, Vansbro, Sweden) to determine maximal aerobic capacity. During the GXT, participants were allowed to find a comfortable pedaling rate they could maintain during both the GXT and exercise trials ( $82 \pm 3$  RPM). Once participants were ready, pedaling resistance started at 0.5 kp and increased by 0.5 kp every 3 min for the first 4 workloads (linear phase), then 0.5 kp every min (max phase) until volitional fatigue. During the GXT, respiratory gases were monitored with online oxygen and carbon dioxide analyzers (Physio-dyne Instrument Corp., Quogue, NY). Peak aerobic capacity ( $\text{VO}_{2\text{peak}}$ ) was used to determine the workrate in steady state exercise and subsequent work in the performance trial.

### *Experimental Protocol*

Volunteers participated in 3 trials separated by at least one week. Prior to each trial, participants kept a 3-d diet (food and fluid) and exercise diary that was replicated prior to subsequent trials. Participants entered the laboratory after an overnight fast ( $> 8$  h) without prior exercise for at least 16 h. To ensure euhydration on testing days, participants also drank at least one extra liter of water the day before the trials.

The trials were completed in a semi-randomized, counterbalanced design. Each trial varied according to the beverage ingested 45 min before exercise and the quantity of water ingested during exercise. The beverage ingested before exercise was either commercially-available bottled water (WATER) or chicken noodle soup (CNS). Table 1 shows the nutrient



profiles of the two experimental beverages. Participants were allowed to drink water *ad libitum* in CNS and WATER. In the third trial, the amount and timing of water ingested during exercise was equal to the chicken noodle soup trial (WATER/R). Water was given at room temperature and CNS was heated to  $\sim 50^{\circ}\text{C}$ . The WATER/R trial was always the final trial so the participants were unaware of how water intake was calculated. Water intake and drinking behavior (volume and timing) during exercise was determined by pre-post drink water bottle weights. Water issued during exercise was at the temperature of the environmental chamber.

Upon entering the laboratory, subjects voided, provided a urine sample, inserted a rectal thermometer (YSI 401, Dayton, OH) to a depth of 10 cm past the anal sphincter, and were fitted with a heart rate monitor (Polar, Electro Oy, Finland). Nude body mass was then recorded to the nearest 0.05 kg (Befour, Inc, Saukville, WI). After 10 min in a seated, resting position, baseline heart rate, blood pressure, rectal temperature, and cognitive performance were recorded. Following baseline measurements, a Teflon indwelling catheter was placed into an antecubital vein and an 8 ml resting blood sample was taken without stasis. Prior to the blood sample, participants indicated their current rating of perceived exertion and thirst (analogue scale). Blood samples were placed in lithium heparin tubes (BD Biosciences, San Jose, CA) from which hematocrit (Hct) and hemoglobin (Hb) concentration was measured immediately before centrifuging at  $400 \times g$  for 10 min. Plasma was immediately analyzed for osmolality and sodium, potassium, and chloride concentrations before being frozen and stored at  $-20^{\circ}\text{C}$  for further analyses. After the pre-ingestion (Pre-I) blood sample was drawn,

participants ingested 355 ml of the experimental beverage and rested for 45 min prior to the onset of steady state exercise.

After 35 min of rest in a thermoneutral environment ( $22.6 \pm 1.0^{\circ}\text{C}$ ,  $31.4 \pm 8.5\%$  RH), participants urinated, nude body mass was recorded, participants mounted the same cycle used in the GXT, and baseline measurements were retaken. Immediately before starting steady state exercise, a resting, seated, pre-exercise blood sample (Pre-Ex) was drawn. Exactly 45 min after ingestion of the experimental beverage, participants began 90 min of exercise in a controlled, heated environment ( $34.4 \pm 0.4^{\circ}\text{C}$ ,  $30.8 \pm 3.1\%$  RH; compensable heat stress) at a workload prescribed to elicit 50%  $\text{VO}_{2\text{peak}}$ . Every 30 min during steady state exercise, all Pre-I and Pre-Ex measurements were retaken with the exception of nude body mass (EX30, EX60, EX90). Expiratory gases were sampled during the last 5 min of each 30-min interval and used to calculate substrate oxidation during exercise by stoichiometric equations (30). Blood samples were also taken every 30 min during steady state exercise and treated as previously described. As a safety measure, exercise was discontinued if rectal temperature exceeded  $39.5^{\circ}\text{C}$ .

Following the steady state exercise phase of the trial, participants urinated, were reweighed nude after toweling dry, remounted their cycle ergometer and prepared for the physical performance phase. The amount of resting time between the steady state and physical performance phases was  $5.9 \pm 1.3$  min. The physical performance task consisted of high intensity exercise and was prescribed as the time to complete the work accumulated in 10 min of exercise at 90%  $\text{VO}_{2\text{peak}}$ . During the physical performance phase, no measurements except rate of work accumulation was recorded and participants were given no

encouragement or indication of time, RPM, and work accumulated except verbal acknowledgement of when they had completed 50 and 100% of the performance task. Water intake during the physical performance task was allowed *ad libitum* in all trials so the participants could exercise undisturbed. After completion of the physical performance task, participants urinated and were weighed nude after toweling dry. Before leaving the laboratory, thirst and a cognitive performance were recorded.

Cognitive performance was assessed as the mean response time and number of errors during 45 s in a computerized version of the Stroop Word/Color test (Wang Neuropsychological Laboratory, San Luis Obispo, California). The Word/Color test is the most complex of the three Stroop tests and is comprised of 3 words (BLUE, GREEN, and RED) printed in a different color than what is represented by the word. Participants must indicate the color of the letters, not the color represented by the printed word. The Stroop word/color test was chosen because of the inhibitory nature of the task, the high level of prefrontal cognitive processing, and cognitive-motor interaction. For consistency, the participants always used their dominant hand and, during exercise, the computer was set on a cart level with their dominant arm with the palm of their hand rested on the computer. Mean response time was calculated with error response times removed.

### *Biochemical Analyses*

Blood samples were analyzed in triplicate for Hb concentration using the cyanmethemoglobin spectrophotometric (Stanbio, Boerne, TX) assay and Hct by microcapillary centrifugation. Hematocrit values were corrected for trapped plasma volume between red blood cells (0.96) and venous-to-total body Hct ratio (0.91; 31). Percent plasma

volume change was calculated using the equations of Dill and Costill (32) with Pre-I measurements as a reference. Total urine volume was measured before the start of exercise and at the end of steady state exercise and the physical performance task. Plasma and urinary osmolalities were measured by freezing point depression (Westcor, Inc., Logan, Utah) and electrolyte concentrations by selective ion electrodes (Medica, Bedford, MA). Plasma glucose concentration was measured by enzymatic spectrophotometric assay (Stanbio Laboratory, Boerne, TX) and urine specific gravity by spectral refractometry (Leica Microsystems, Inc., New York). All plasma and urine measurements were performed in duplicate.

#### *Calculations*

Fluid balance was calculated as the difference between Pre-I and post steady state body mass after urination and was used as an indicator the preexercise beverages effectiveness in increasing water intake and reducing urine losses after 45 min rest and subsequent steady state exercise. Fluid balance was not assessed during physical performance task because of differences in performance time and intensity.

The effectiveness of pre-exercise beverages to reduce urinary water loss independent of water intake during exercise was determined by calculating the percent water retention as shown in equation 1. In this equation, total fluid ingested is the mass of the preexercise beverage plus water ingested (g) during steady state exercise and total urine mass is the estimated urine mass (urine volume x specific gravity; g) after 45 min of rest and 90 min of steady state exercise.

$$\% \text{ water retention} = [(\text{total fluid ingested} - \text{total urine mass}) / \text{total fluid ingested}] \times 100 \quad (1)$$

Percent dehydration after steady state exercise was calculated as the percent change in body mass from Pre-I to end of steady state exercise (after urination). Percent dehydration expresses fluid balance normalized to body mass. Again, because of individual differences in physical performance, percent dehydration after steady state exercise was used instead of whole trial dehydration.

The mass of water consumed with each drink and the time at which the drink was taken during both steady state exercise and subsequent physical performance task was recorded in order to classify drinking behavior by the rate of water intake (g/min), the volume of water per drink (g/drink), and the time between drinks (min/drink).

Osmotic (OC) and free water (FWC) clearance rates were calculated as shown in equations 2 and 3, respectively (33). In these equations, mean rate of urine accumulation ( $V$ ; g/min) during steady state exercise was determined by dividing urine mass by time spent in steady state exercise (90 min). An integrated mean plasma ( $POsm_{ave}$ ) osmolality was used due to multiple measurements during steady state exercise. Because urine was collected after steady state exercise, EX90 urine osmolality represents the mean during steady state exercise ( $UOsm_{ave}$ ).

$$OC \text{ (g/min)} = V \times UOsm_{ave} / POsm_{ave} \quad (2)$$

$$FWC \text{ (g/min)} = V - OC \quad (3)$$

Heat storage ( $\text{W/m}^2$ ) was calculated according to Armstrong et al. (34) as shown in equation 4 where 0.97 represents the mean specific heat of body tissues,  $BW_{\text{pre}}$  is preexercise body mass,  $(Tb_{\text{post}} - Tb_{\text{pre}})$  represents the change in rectal temperature during exercise, SA is body surface area ( $\text{m}^2$ ), and t is exercise duration (h). Surface area (equation 5) was calculated according to DuBois & Dubois (35) where Ht is height (m) and Wt is body mass (kg).

$$HS = [0.97BW_{\text{pre}}(Tb_{\text{post}} - Tb_{\text{pre}})] / (SA \times t) \quad (4)$$

$$SA = 0.20247 \times Ht^{0.725} \times Wt^{0.425} \quad (5)$$

### *Statistical Analyses*

All statistics were performed using Sigma Stat statistical software (Systat Software, Inc., San Jose, CA). Pre-trial indices of dietary and physical activity control, urine variables (total urine volume, sodium, potassium, and chloride), fluid balance, % dehydration, % water retention, total carbohydrate (TotCHO) and fat (TotFAT) oxidized, physical performance time, mean work accumulation rate in the physical performance task, and mean wet-bulb globe temperature (WBGT) were analyzed using one-way repeated measures analyses of variance (ANOVA). One participant was unable to finish the required work during the physical performance task and all his performance data were excluded ( $n = 8$ ). Mean exercise  $\text{VO}_2$ , carbohydrate ( $\text{CHO}_{\text{ox}}$ ) and fat ( $\text{FAT}_{\text{ox}}$ ) oxidation rates, blood plasma variables (% plasma volume change, glucose, sodium, potassium, and chloride concentrations, and osmolality), urine variables (osmolality and specific gravity), blood pressure, heart rate, rectal

temperature, and ratings of perceived exertion and were subjected to two-way repeated measures ANOVA. Some individuals were unable to urinate at specific time intervals so analyses were only run with those who had complete data (Pre-I, Pre-Ex, and EX90) for urine osmolality and specific gravity ( $n = 7$ ). Because drinking behavior was controlled during the WATER/R trial, only WATER and CNS data were included in the analyses. Interior standard deviation bars have been removed to prevent obscuring of internal data points. Significant trial, time, and/or time by trial interaction effects were evaluated further using Holm-Sidak post hoc analyses where appropriate. Data are reported as means  $\pm$  SD and statistical differences were declared if  $p < 0.05$ .

## **Results**

### *Baseline Observations*

Selected baseline control variables are shown in Table 2. No effect of trial was observed for baseline body mass, urine specific gravity or osmolality, plasma osmolality or glucose concentration, rectal temperature, or ambient or chamber wet bulb globe temperatures. Baseline urine and plasma electrolytes were also similar for each trial. Perceived thirst was also similar before ingestion of the experimental beverage. Mean reaction time in the Stroop word/color test tended to be lower in WATER/R ( $0.66 \pm 0.10$  vs.  $0.74 \pm 0.09$  and  $0.83 \pm 0.31$  s vs. WATER and CNS, respectively;  $p = 0.08$ ). The lower reaction time in WATER/R is likely due to a learning effect because the WATER/R trial was the last trial for all participants.

### *Substrate Oxidation*

Mean  $\text{VO}_2$  and during state exercise was similar for all trials. Carbohydrate and fat oxidation rates were independent of trial and time by trial interaction, respectively. However, a typical increase in  $\text{FAT}_{\text{ox}}$  was observed as during steady state exercise ( $p < 0.001$ ). Total carbohydrate and fat oxidized during steady state exercise was similar for all trials.

### *Fluid Balance*

*Ad libitum* water intake after CNS was greater than WATER throughout the entire 90 min of steady state exercise ( $1434 \pm 593$  vs.  $1163 \pm 427$  g, respectively;  $p = 0.007$ ; Table 3). When drinking behavior was broken down into 30-min intervals, the volume of water per drink was not different between WATER and CNS; however, because CNS tended to have a greater number of drinks per time interval (trial effect  $p = 0.08$ ), when these two variables were multiplied to calculate total volume at each interval, CNS increased water intake compared with WATER (trial effect  $p = 0.03$ ; Table 3). Total water intake during WATER/R ( $1427 \pm 595$  g) was similar to CNS. Water intake during the physical performance task was lower in WATER/R compared with WATER and CNS ( $158 \pm 138$  vs.  $302 \pm 236$  and  $332 \pm 244$  g, respectively;  $p = 0.004$ ). Ratings of perceived thirst were suppressed in WATER/R after 60 min of exercise compared with WATER and at the end of steady state exercise compared with WATER and CNS (Figure 1).

Total urine output for the entire trial was not dependent on the beverage ingested before exercise or the amount of water ingested during exercise ( $353 \pm 246$ ,  $229 \pm 196$ , and  $292 \pm 192$  ml for WATER, CNS, and WATER/R, respectively). Trial water retention (%) was also independent of preexercise beverage and water intake during exercise despite marked differences in free water clearance (Figure 2). Free water clearance was negative in



CNS ( $-0.3 \pm 1.2$ ) and was positive in both WATER and WATER/R ( $0.5 \pm 1.1$  and  $0.6 \pm 1.0$ , respectively;  $p = 0.02$ ). Osmotic clearance was not different by trial ( $p = 0.6$ ). Total sodium, potassium, and chloride outputs were similar in all trials ( $p = 0.7$  for all). Urine specific gravity and osmolality were lower ( $p = 0.02$  and  $0.007$ , respectively;  $n = 7$ ) in WATER and WATER/R after 90 min of exercise compared with baseline and in CNS after 90 min of exercise. Calculated evaporative losses (change in body mass + water intake during steady state exercise) were also similar through 90 min of steady state exercise ( $1.1 \pm 0.2$ ,  $1.1 \pm 0.3$ , and  $1.2 \pm 0.2$  for WATER, CNS, and WATER/R, respectively).

Fluid balance after CNS ingestion was higher compared with WATER but not WATER/R ( $-0.11 \pm 0.60$  vs.  $-0.48 \pm 0.59$  and  $-0.23 \pm 0.67$  kg, respectively; Figure 3). Percent dehydration was lower indicating an improved hydration status with CNS compared with WATER but not WATER/R ( $-0.10 \pm 0.78$  vs.  $-0.61 \pm 0.79$  and  $-0.26 \pm 0.85\%$ , respectively;  $p < 0.05$ ).

#### *Plasma Constituents*

Plasma osmolality increased during exercise similarly were similar for all trials despite a greater intake of electrolytes and macronutrients in CNS compared with both water trials (Figure 4A). Figure 4 (B-D) shows plasma electrolyte concentrations during rest and 90 min of steady state exercise. Plasma sodium concentrations were greater in the CNS trial compared with WATER/R but not WATER (trial effect  $p = 0.02$ ). Plasma potassium concentrations were similar for all trials with a marked increase before exercise and during exercise ( $p < 0.001$ ). Plasma chloride concentrations were greater throughout exercise compared with rest and were higher in CNS compared with WATER/R. Plasma volume was

higher after CNS compared with WATER and WATER/R before and throughout exercise (Figure 5). Plasma glucose concentrations were similar for all trials.

#### *Temperature Regulation, Cardiovascular Control, and RPE*

Rectal temperatures were similar in CNS and WATER throughout steady state exercise. A reduction in rectal temperature was observed in WATER/R possibly indicating a heat acclimation effect ( $p = 0.02$ ; Figure 6). Rectal temperatures increased normally at each interval during exercise compared with rest and the previous interval ( $p < 0.001$ ). Although rectal temperature was consistently lower in WATER/R, heat storage during 90 min of exercise was similar for all trials ( $42.5 \pm 11.8$ ,  $38.7 \pm 8.3$ , and  $39.1 \pm 15.5$  W/m<sup>2</sup>;  $p = 0.4$ ). Heart rate (Figure 7) was greater in CNS and WATER compared to WATER/R after 90 min of exercise. Systolic blood pressure was lower after 30 min of exercise compared with CNS and WATER/R. Perceived exertion ratings were similar for all trials.

#### *Physical and Cognitive Performance*

The mean work the participants were required to complete in 10 min during the physical performance task was  $155.6 \pm 22.1$  kJ ( $n = 8$ ). The time to complete the prescribed amount of work was independent of preexercise beverage composition and water intake during exercise ( $13.9 \pm 2.1$ ,  $14.0 \pm 2.4$ , and  $13.1 \pm 1.4$  min for WATER, CNS, and WATER/R, respectively;  $p = 0.13$ ). A significant order effect does exist for physical performance with improved physical performance in the final trial (WATER/R) compared with the first trial.

Mean reaction time in the Stroop Word/Color test decreased during exercise and after the physical performance task compared with rest ( $p < 0.001$ ; Figure 8). However, the

number of errors also increased late in exercise (EX90) compared with Pre-I ( $p = 0.007$ ; Figure 9). Cognitive performance also showed an order effect with improved performance in trials 2 and 3 (WATER/R) compared with the participants first trial ( $p < 0.001$ ).

## Discussion

Chicken noodle soup ingested 45 min before exercise improved fluid balance due to an increase *ad libitum* water intake during 90 min of steady state exercise compared with an equal volume of water. When water intake was separated into 30-min intervals to investigate the continued effects of soup ingestion, we observed a significant trial effect ( $p = 0.03$ ; Table 3) caused by an increase in water intake throughout steady state exercise. Normal *ad libitum* water intake during exercise replaces approximately 70% of total water losses (36,37). In this study, participants replaced 89% of their total water losses with chicken noodle soup compared with 72% and 80% after water ingestion (*ad libitum* and regulated, respectively). These rates are higher than expected and reported in our last study (68% with chicken noodle soup). The greater water intake may reflect the higher trained status of the participants in the study and/or the additional heat stimulus applied to the participants (38). This study provides additional support for greater water intake throughout exercise after chicken noodle soup ingestion despite mild preexercise hyperhydration.

Fluid intake during and after exercise is regulated by beverage temperature, flavor, and electrolyte content (36,39-42). Fluid intake during exercise is also influenced by the composition of beverages ingested before exercise including beverages that contain high concentrations of carbohydrates and low sodium content (carbohydrate/electrolyte beverage; N. M. Johannsen, unpublished observations). However, in order to maximize the effects of

experimental beverages, high electrolyte content, especially sodium, is required in order to improve water retention (N. M. Johansen, unpublished observations; 42-48). In the current study, we observed no differences in urine output or percent water retention with soup ingestion before exercise. Kidney function was altered as indicated by calculated free water clearance (Figure 2). Interestingly, only preexercise ingestion of soup resulted in a negative free water clearance rate indicating a propensity for the kidneys to conserve water.

Several major differences exist between our previous study and the current experiment. First, we expected that plasma osmolality would increase after chicken noodle soup ingestion as we have previously observed (N. M. Johannsen, unpublished observations). An increase in plasma osmolality has been tied to thirst, kidney function, and other central nervous system mechanisms involved with body fluid homeostasis (49-53). The increases in plasma osmolality observed in the first preexercise study, independent of plasma sodium content, were later replicated in a resting soup feeding study (N. M. Johannsen, unpublished observations). In this study, participants ingested either 355 ml of water, chicken noodle soup (167 mM sodium), or water plus sodium chloride (166.8 mM sodium) before 2 hours of rest. Chicken noodle soup and salt water induced similar increases in plasma osmolality that persisted throughout the two hours of rest. The inclusion of macronutrients and electrolytes in the chicken noodle soup induced changes much quicker than ingestion of salt water alone (15 vs. 60 min). Similar to our first study, the increased plasma osmolality after chicken noodle soup failed to stimulate thirst, but did reduce urine output during the last 75 min of rest. In the present investigation, plasma osmolality was similar in all trials and plasma sodium concentrations were higher after chicken noodle soup compared with regulated water

intake. Closer examination of Figure 4A shows a similar trend for augmented plasma osmolality after soup ingestion compared with water ingestion. The effect size for the increase in plasma osmolality in this study ( $ES = 0.93$ ) was similar to our previous observations ( $ES = 1.05$ ). The lack of statistical differences in plasma osmolality may be related to the small sample size and reduced statistical power. Future research should further investigate the independent effects of increased plasma osmolality without sodium intake on thirst, drinking behavior, and water retention during exercise.

Plasma volume varied according to beverage ingested before and water intake during exercise in the heat. We observed a similar increase in plasma volume in the previously mentioned resting chicken noodle soup feeding study (N. M. Johannsen, unpublished observations). The increase in plasma volume after soup ingestion may be related to the rapid influx of electrolytes and/or macronutrients from the intestine to the plasma leading to apparent isoosmotic hypervolemia. The dilution of plasma constituents after water ingestion could explain the outflow of water into the tissues (negative plasma volume change) and the increase in plasma electrolyte concentrations after soup ingestion would cause water influx to intravascular water. However, this effect on plasma volume has not been observed by other researchers (54-58).

Contrary to our second hypothesis, the ~ 350 ml of additional fluid incorporated into body tissues did not improve cardiovascular function, temperature regulation, or physical or cognitive performance. Improved fluid balance in the heat increases stroke volume, sweat responsiveness, skin blood flow, and sweat rate resulting in improved evaporative cooling, reduced heat storage, and lower core body temperature (1,3,6,18,34), and improves physical

performance, especially in endurance related tasks (11,12,14,59). Although cognitive performance with hypohydration depends on the type of task (15-17, 60,61), decrements have been observed with as little as 2% dehydration (60,61). Evaporative water losses in this study were fairly low ( $\sim 1.0$  l/h) compared with previous research (1.0 - 3.0 l/h; 1,62,63) and dehydration was mild (-0.6%) in the *ad libitum* water trial. We expected the heat stress to cause higher sweat rates and percent dehydration leading to greater cardiovascular and thermoregulatory strain and physical and cognitive performance differences. Although the level of dehydration was not sufficient to induce physiologic decrements, we did observe an increase in the number of errors after 90 min of exercise in the Stroop Word/Color task indicating a cognitive deficit possibly related to a decline in decision making ability by the prefrontal cortex. Future research should include a no fluid/water ingestion trial to serve as a control and provide a greater heat stress to examine whether  $\sim 350$  ml ( $\sim 0.5\%$  body mass) of added body water improves physiologic function.

Our final hypothesis was that water intake equal to the chicken noodle soup trial after water hyperhydration would reduce plasma osmolality resulting in greater urine volumes and decreased perceived thirst. While significant reductions in plasma osmolality and water retention were not observed in the regulated water trial, the additional water intake reduced perceived thirst due to either a loss of drinking control or an oropharyngeal or gastric stretch response associated with greater water intake. Past research points toward the latter as a potential mechanism for this change. Figaro and Mack (38) found that perceived thirst was greater when dehydrated humans were intragastrically infused fluids compared with drinking a similar quantity of water. In addition, *ad libitum* water intake during rest after the initial

bolus of intragastrically infused or ingested water was lower indicating not only a change in thirst perception, but also a functional difference in dipsogenic drive. We observed a similar reduction in thirst as Figaro and Mack (38) during the physical performance task. Dipsogenic drive, evidenced *ad libitum* water intake in the physical performance task, was reduced compared with both *ad libitum* water intake trials.

In conclusion, chicken noodle soup ingestion 45 min before exercise improved fluid balance by persistently augmenting *ad libitum* water intake throughout before 90 min of steady state exercise at 50%  $\text{VO}_{2\text{peak}}$  under compensable heat stress. Although the improved fluid balance resulted in greater plasma volume expansion compared with *ad libitum* and regulated water intake, no cardiovascular, temperature regulatory, or physical or cognitive performance benefits were observed. Future research should further investigate the mechanisms for the increase in water intake and plasma expansion observed after chicken noodle soup ingestion. In addition, greater thermal stress could be used to determine to what point the additional body fluid has improves physiologic and cognitive variables.

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## Tables and Figures

**Table 1.** *Beverage Composition*

	WATER	CNS
Osmolality, (mosmol/kg)	6.5	382.5
[Na <sup>+</sup> ], mmol/l	3.1	166.9
[K <sup>+</sup> ], mmol/l	0.0	6.9
[Ca <sup>2+</sup> ], mmol/l	0.0	2.9
Total CHO, g/l	0.0	46.5
Simple Sugar, g/l	0.0	1.5
Total Fat, g/l	0.0	7.0
Total Protein, g/l	0.0	15.0

Osmolality of CNS determined on liquid fraction. Electrolyte and nutrient concentrations for CNS determined by homogenation. WATER, commercially available bottled water; CNS, chicken noodle soup; [Na<sup>+</sup>], [K<sup>+</sup>], and [Ca<sup>2+</sup>]; sodium, potassium, and calcium concentration; CHO, carbohydrate.



**Table 2.** *Selected baseline control variables.*

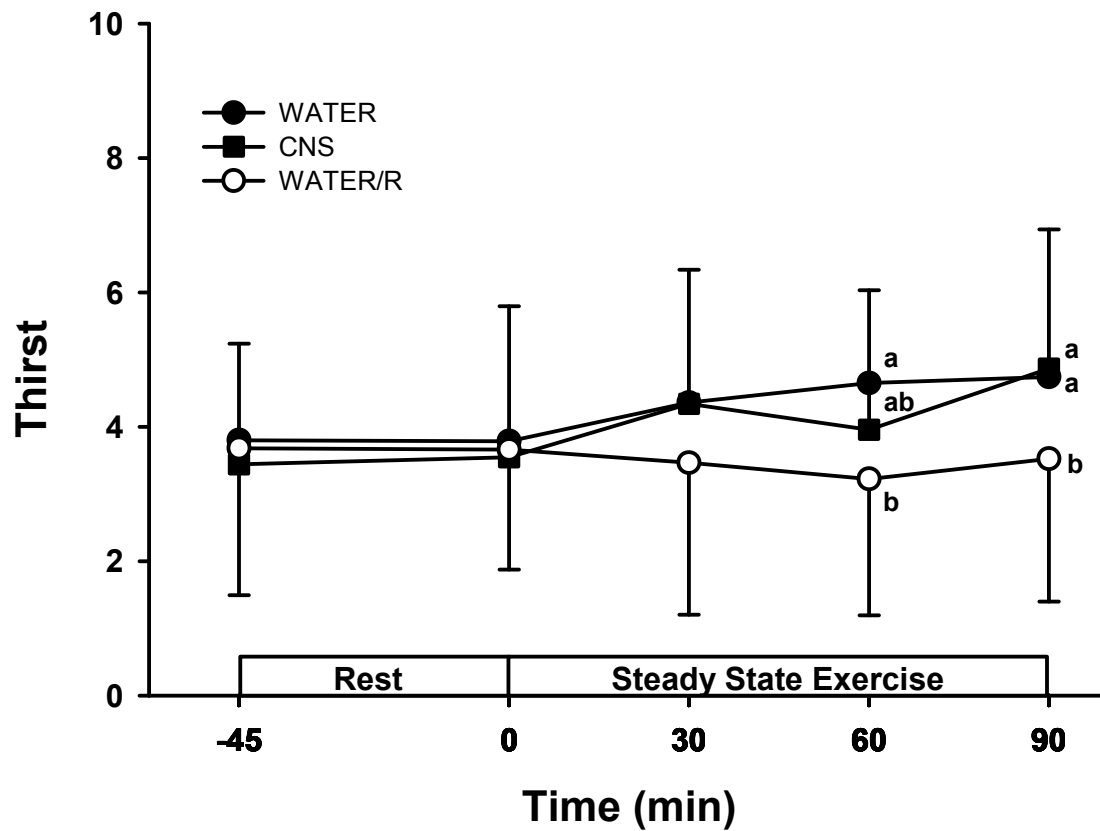
	WATER	CNS	WATER/R
<b>Body Weight (kg)</b>	75.1 ± 6.7	75.0 ± 6.9	75.1 ± 6.7
<b>Urine</b>			
Specific Gravity	1.017 ± 0.007	1.018 ± 0.005	1.016 ± 0.005
Osmolality (mOsm/kg)	639.2 ± 260.6	680.7 ± 184.2	615.1 ± 199.8
<b>Plasma</b>			
Osmolality (mOsm/kg)	280.9 ± 6.4	281.1 ± 4.3	282.9 ± 3.0
Glucose (mM)	5.4 ± 0.7	5.2 ± 0.4	5.4 ± 0.7
<b>Rectal Temperature (°C)</b>	37.01 ± 0.28	37.04 ± 0.20	36.89 ± 0.27
<b>Ambient WBGT (°C)</b>	16.6 ± 0.6	16.6 ± 0.4	16.7 ± 0.6
<b>Chamber WBGT (°C)</b>	25.8 ± 0.2	25.9 ± 0.5	25.5 ± 0.5

All data are means ± SD. WATER, commercially available bottled water + ad libitum water in exercise; CNS, chicken noodle soup + ad libitum water in exercise; WATER/R, commercially available bottled water + regulated water intake to CNS in exercise; WBGT, calculated wet bulb globe temperature. No effects of trial exist for any of the control variables.

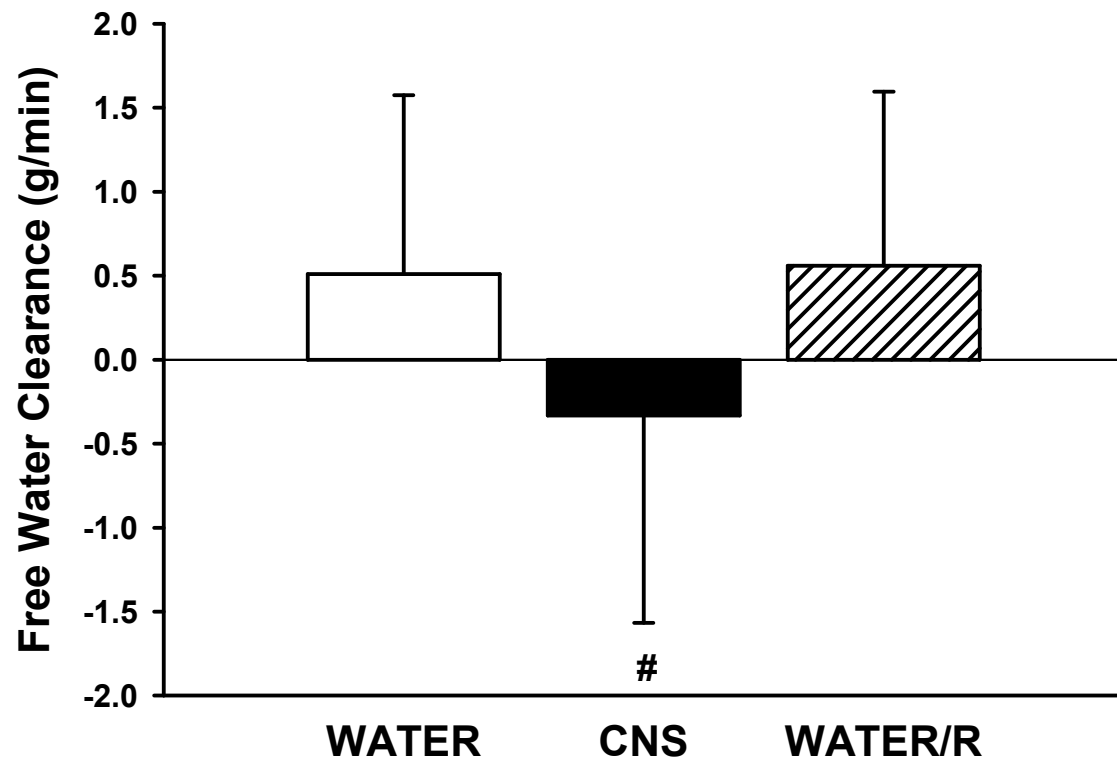
**Table 3.** *Drinking behavior during 90 min of steady state exercise at 50%  $VO_{2peak}$  under compensable heat stress.*

	WATER	CNS
<b>Total Water Intake (g)</b>	<b>1163 ± 427</b>	<b>1434 ± 592</b>
0 - 30 min	355 ± 280	410 ± 314
30 - 60 min	391 ± 203	502 ± 210
60 - 90 min	417 ± 208	522 ± 226
<b>Total Number of Drinks</b>	<b>15.0 ± 7.5</b>	<b>17.9 ± 8.6</b>
0 - 30 min	4.3 ± 3.0	4.9 ± 2.9
30 - 60 min	5.4 ± 3.1	6.1 ± 2.3
60 - 90 min	5.2 ± 3.4	6.9 ± 3.9
<b>Total Volume/Drink (g)</b>	<b>93.2 ± 62.4</b>	<b>92.6 ± 59.0</b>
0 - 30 min	90.9 ± 67.5	90.6 ± 75.4
30 - 60 min	88.7 ± 57.8	90.6 ± 53.4
60 - 90 min	97.6 ± 59.7	91.4 ± 51.2

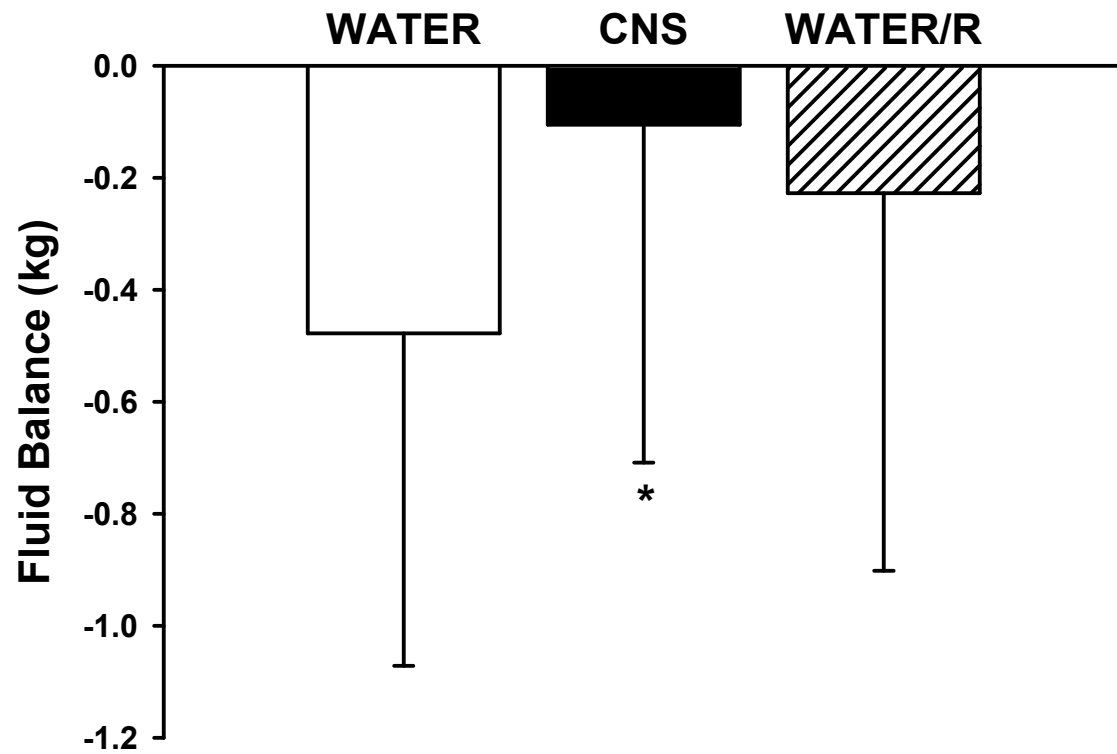
All data are means ± SD. WATER, commercially available bottled water + *ad libitum* water in exercise; CNS, chicken noodle soup + *ad libitum* water in exercise. Total drinking behavior analyzed using one-way repeated measures ANOVA's. Time interval data analyzed using two-way repeated measures ANOVA's. Trial effects for both total ( $p = 0.007$ ) and interval water intake ( $p = 0.03$ ) exist due to increased water intake in CNS.



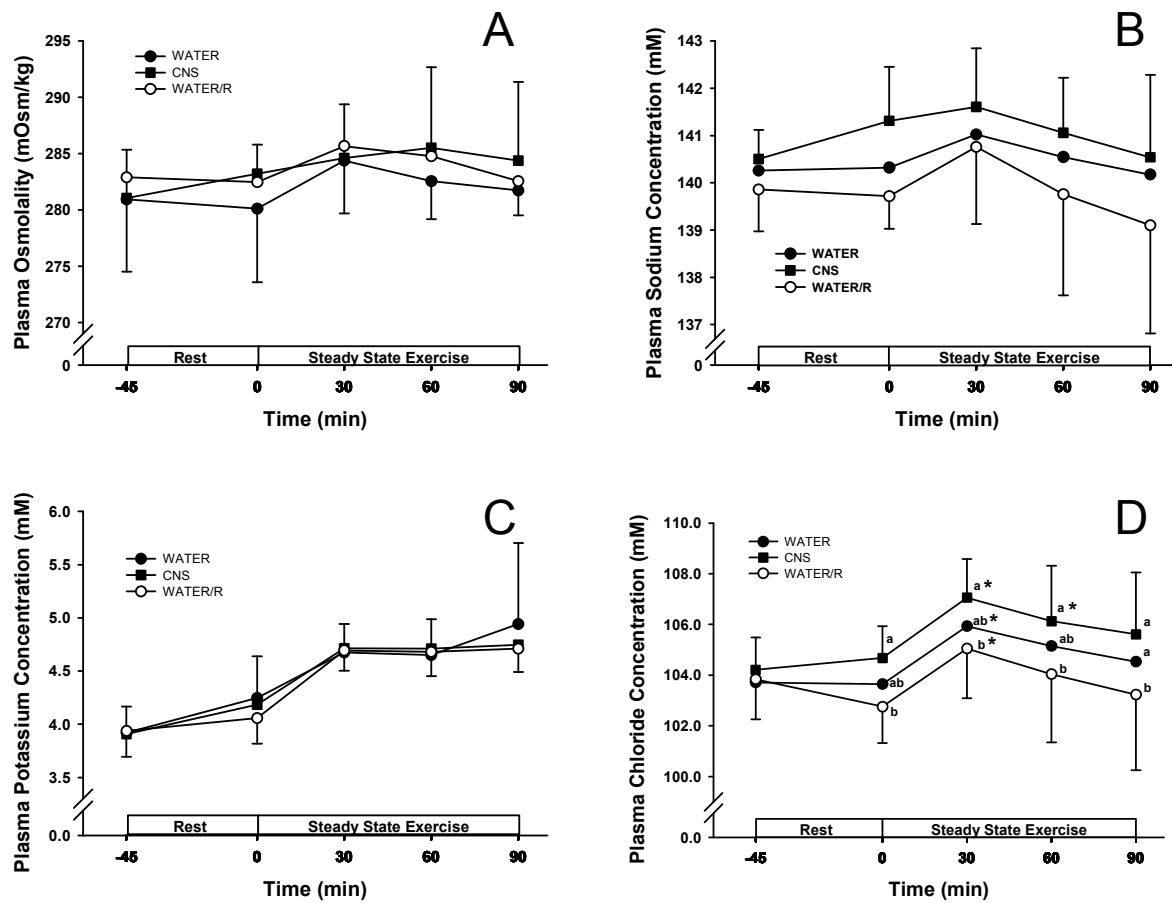
**Figure 1.** Rating of perceived thirst during 90 min of exercise at 50%  $\text{VO}_{2\text{peak}}$  under compensable heat stress was dependent on preexercise beverage intake and water intake during exercise (means  $\pm$  SD). An interaction of trial and time ( $p = 0.05$ ) existed. Dissimilar letters are different between trials at a given time point. For all graphs, -45 (Pre-I), 0 (Pre-Ex), 30 (EX30), 60 (EX60), and 90 (EX90) represent the time relative to the start of steady state exercise.



**Figure 2.** Free water clearance during 90 min of exercise at 50%  $\text{VO}_{2\text{peak}}$  under compensable heat stress was dependent on preexercise beverage with CNS ingestion resulting in water conservation by the kidney (means  $\pm$  SD). An effect of trial exists ( $p = 0.02$ ). # different than both WATER and WATER/R.

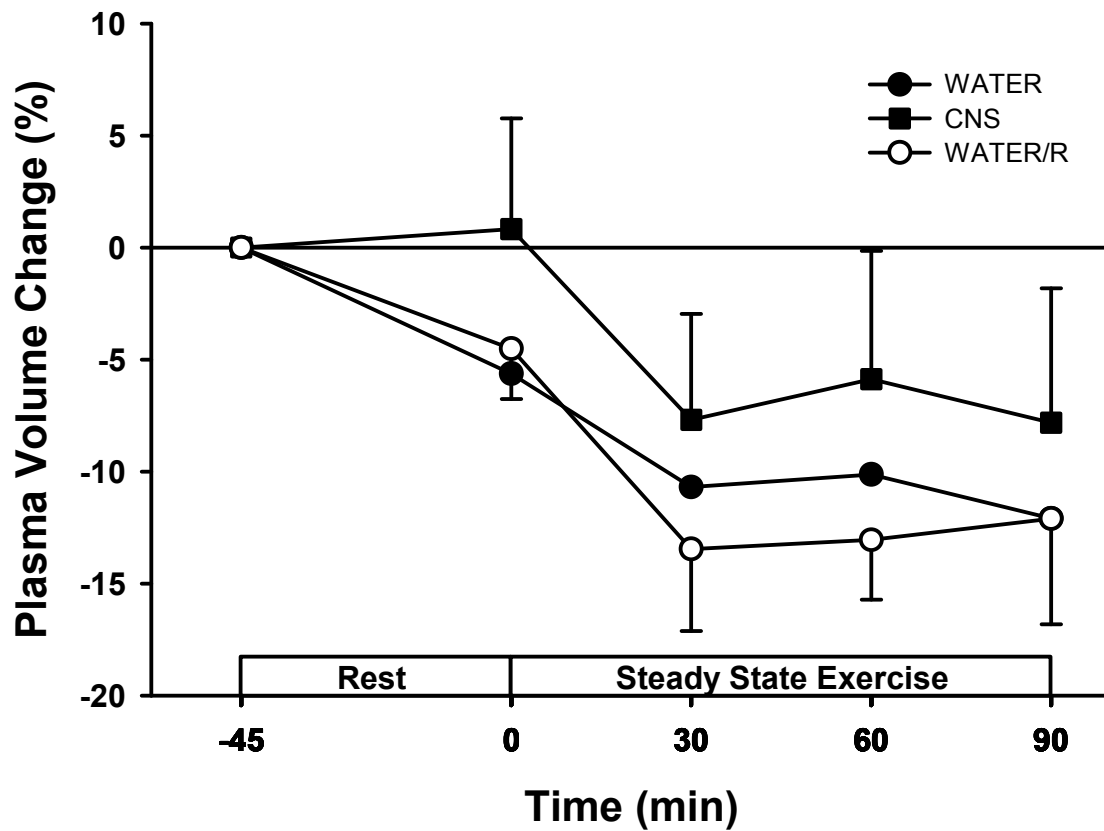


**Figure 3.** Fluid balance after 90 min of exercise at 50%  $\text{VO}_{2\text{peak}}$  under compensable heat stress was improved after CNS ingestion (means  $\pm$  SD). An effect of trial exists ( $p < 0.05$ ). \* different that WATER.

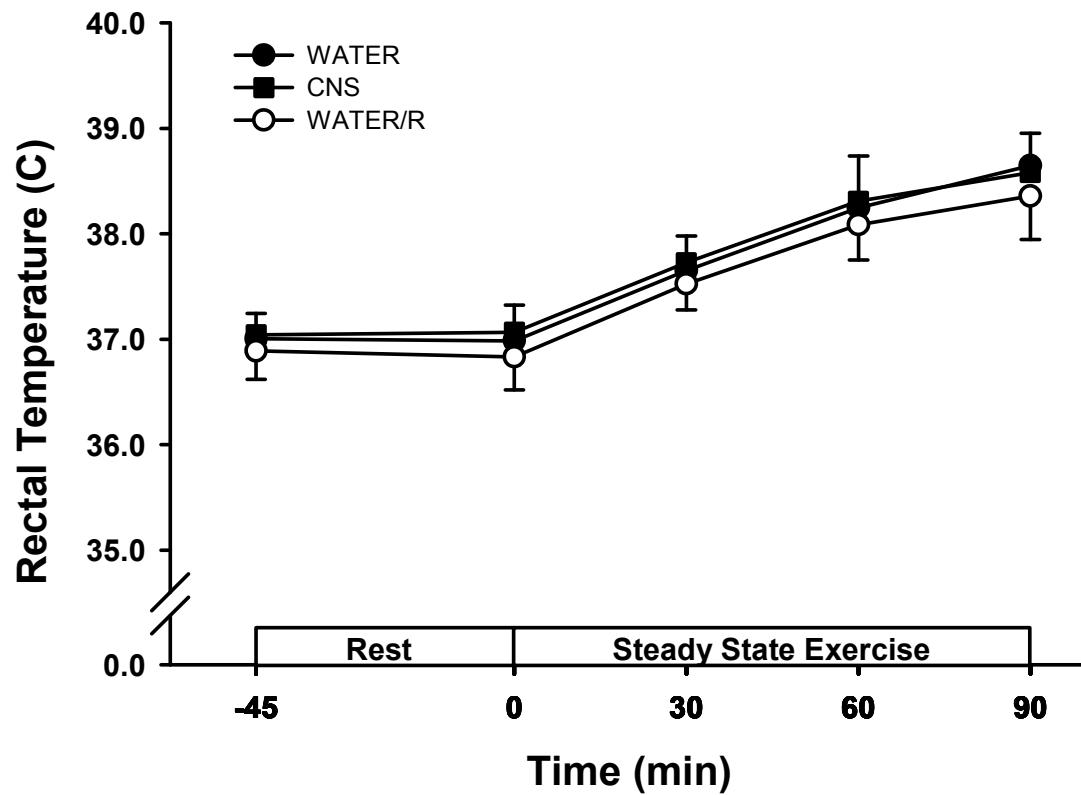


**Figure 4.** Plasma osmolality (A), sodium (B), potassium (C), and chloride (D)

concentrations during rest and 90 min of steady state exercise at 50%  $\text{VO}_{2\text{peak}}$  under compensable heat stress (means  $\pm$  SD). Plasma osmolality showed an effect of time ( $p = 0.03$ ), plasma sodium an effect of trial ( $p = 0.02$ ;  $\text{CNS} < \text{WATER/R}$ ), plasma potassium an effect of time ( $p < 0.001$ ; rest < exercise and Pre-I < Pre-Ex), and plasma chloride effects of trial ( $p < 0.01$ ), time ( $p < 0.001$ ), and trial by time interaction ( $p < 0.001$ ). Dissimilar letters show differences between trials at a given time point and \* is different from rest.

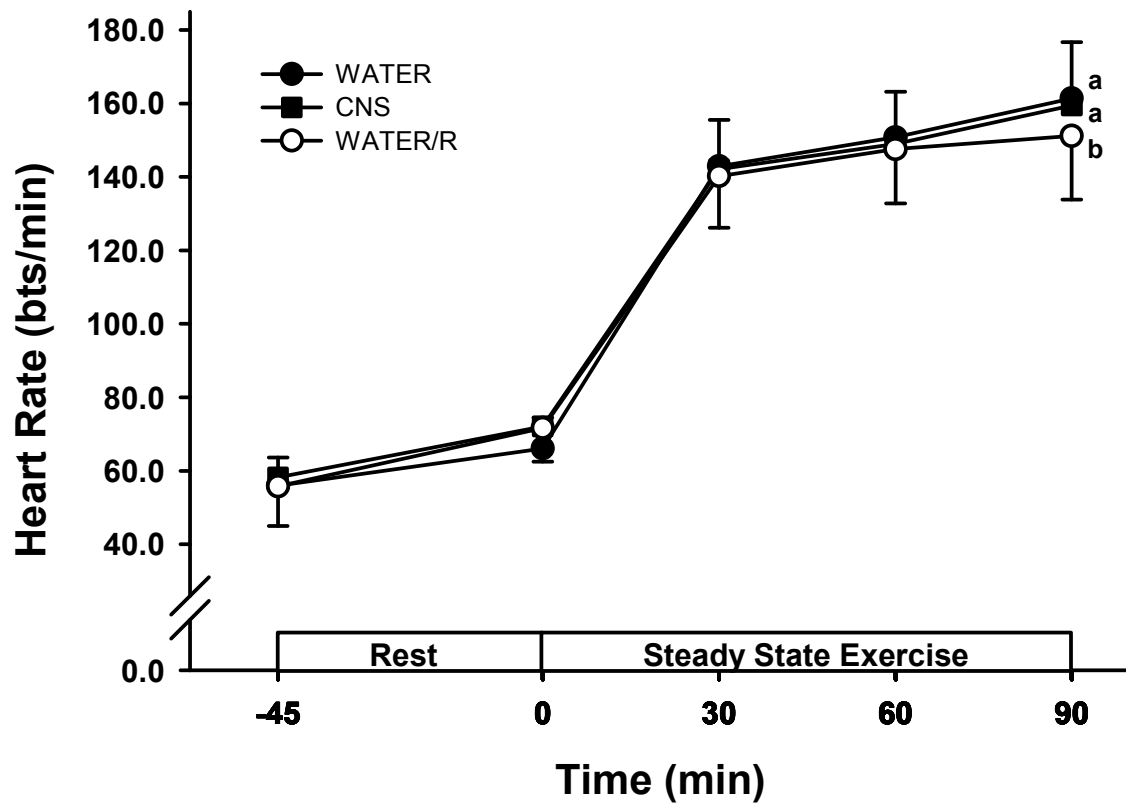


**Figure 5.** Percent change in plasma volume during rest and 90 min of steady state exercise at 50%  $\text{VO}_{2\text{peak}}$  under compensable heat stress was improved after CNS compared with WATER and WATER/R (means  $\pm$  SD). Effects of trial ( $p = 0.01$ ; CNS > WATER, WATER/R) and time ( $p < 0.001$ ; Pre-Ex > exercise) exist.

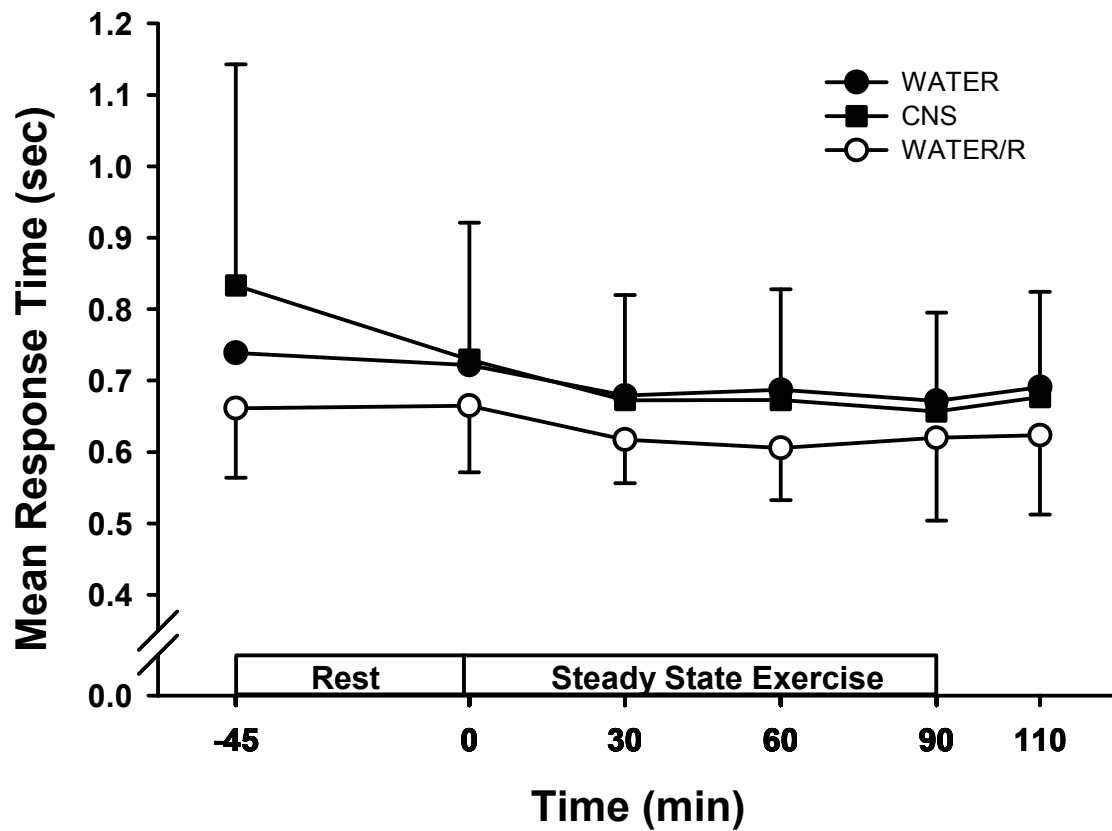


**Figure 6.** Rectal temperature response during rest and 90 min of steady state exercise at 50%  $\text{VO}_{2\text{peak}}$  under compensable heat stress was improved in WATER/R compared with WATER and CNS (means  $\pm$  SD). Effects of trial ( $p < 0.02$ ) and time ( $p < 0.001$ ; Pre-I, Pre-EX < EX30 < EX60 < EX90) exist.

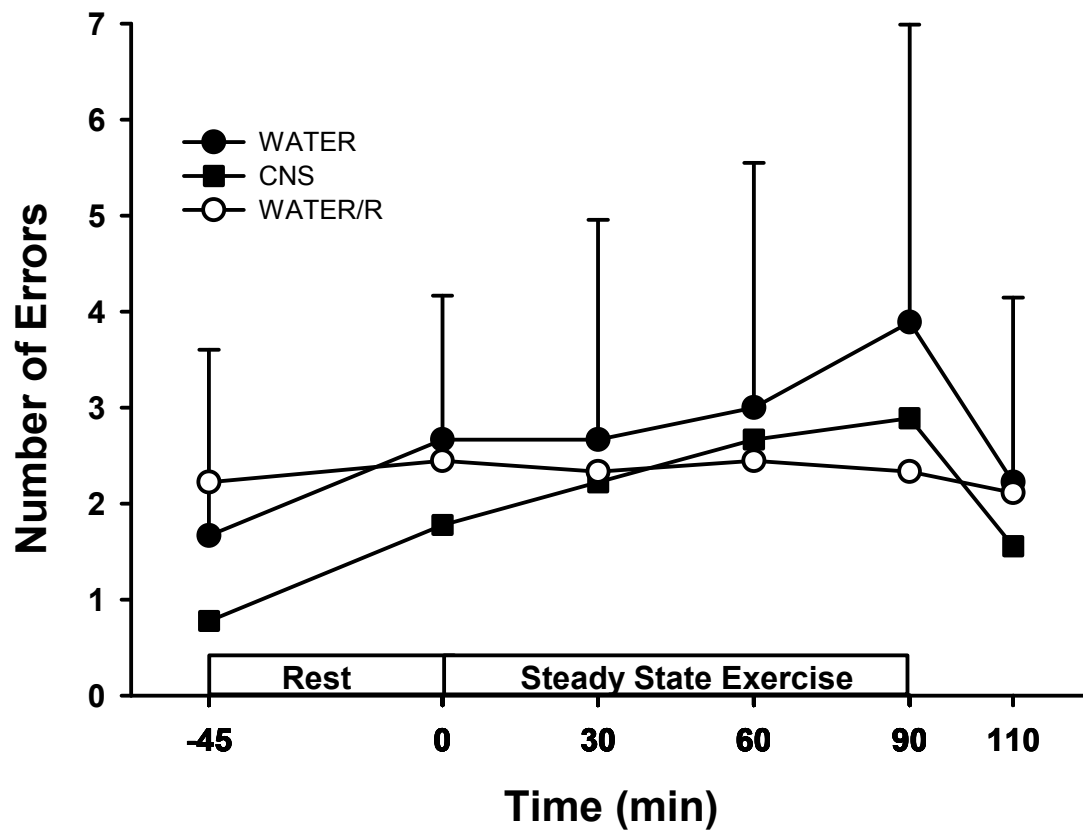




**Figure 7.** Heart rate response during rest and 90 min of steady state exercise at 50%  $\text{VO}_{2\text{peak}}$  under compensable heat stress was dependent on preexercise beverage composition and water intake (means  $\pm$  SD). Effects of time ( $p < 0.001$ ; Pre-I < Pre-EX < EX30 < EX60 < EX90) and trial by time interaction ( $p < 0.02$ ) exist. Dissimilar letters are different between trials at a given time point.



**Figure 8.** Mean response time in Stroop word/color cognitive task during 90 min of steady state exercise at 50%  $\text{VO}_{2\text{peak}}$  under compensable heat stress was independent on preexercise beverage composition and water intake (means  $\pm$  SD). Time 0 min is cognitive evaluation immediately after the onset of exercise and 110 min is immediately after cessation of the physical performance task. An effect of time ( $p < 0.001$ ) exists due to improved performance during exercise compared with rest. An order effect also exists (trial effect  $p < 0.001$ ) in which the first trial had greater time to answer than the second and third trials.



**Figure 9.** Number of errors in the Stroop word/color cognitive task during 90 min of steady state exercise at 50%  $\text{VO}_{2\text{peak}}$  under compensable heat stress was independent on preexercise beverage composition and water intake (means  $\pm$  SD). Time 0 min is cognitive evaluation immediately after the onset of exercise and 110 min is immediately after cessation of the physical performance task. An effect of time ( $p < 0.01$ ) exists due to an increase in the number of errors after 90 min of exercise compared with rest.

## CHAPTER 6. CONCLUSIONS

The main finding of this dissertation is that ingestion of 355 ml of chicken noodle soup before exercise persistently augments water intake throughout 90 min moderate intensity exercise resulting in improved fluid balance compared with a similar quantity of water. The degree to which water intake increased after chicken noodle soup ingestion compared with water during exercise was independent of environmental condition (215 vs. 272 ml for thermoneutral vs. hot, dry environments, respectively), even though the rate of water intake was approximately twice as high in the heat. The final project in this dissertation demonstrates that ingestion of chicken noodle soup increases perceptions of thirst leading to greater rates of water intake. The evidence for this mechanism is the comparison between the *ad libitum* and regulated water ingestion trials. When water intake during exercise was forced at a rate equal to that of the chicken noodle soup trial, rating of perceived thirst decreased significantly. We originally hypothesized that the additional water ingested in the regulated water trial would concurrently lower plasma osmolality resulting in a reduction in perceived thirst, but we did not find the consistent plasma osmolality differences in the final project initially reported in the first two projects (chapter 3; figure 5; chapter 4, figure 1). Unfortunately, we did not determine the rates of gastric emptying or intestinal absorption to determine whether the change in perceived thirst was the result of GI distention or changes in plasma constituents.

Another main finding in this research was that despite an increase in water intake during exercise, percent water retention was improved after ingesting chicken noodle soup compared with water in the first two studies. The consistent improvement in fluid balance in

the two exercise studies supports this claim. Fluid balance was greater in both studies after ingestion of chicken noodle soup compared with water. The regulated water intake trials in both studies suggest that at least part of the fluid balance improvements are due to water retention. In the initial exercise study in the thermoneutral environment, the regulated trial was a repeated chicken noodle soup trial with lower rates of water intake (equal to the carbohydrate/electrolyte trial). Fluid balance in this regulated soup trial was still different than the water trial, but was intermediate between the unregulated soup and carbohydrate/electrolyte trials. Similarly, fluid balance in the culminating project was improved when water was regulated in the second preexercise water ingestion trial, but the increase in water intake alone could not explain the improvements in fluid balance after chicken noodle soup ingestion.

Although urine output was not different in the final project, we calculated free water clearance as a surrogate measure for reduced kidney water output. Similar to the first exercise study, the final project showed a significant reduction in urinary water output indicated by a lower free water clearance. Interestingly, chicken noodle soup ingestion before exercise produced negative free water clearance rates in the heat study compared with positive values after water ingestion indicative of water retention. Together, the findings from these studies provide evidence that chicken noodle soup ingestion before exercise improves fluid balance due to simultaneous effects on *ad libitum* water intake and conservation of water by the kidneys.

Another novel finding in this study was the maintenance of plasma sodium concentrations after chicken noodle soup ingestion compared with water ingestion when rates

of water intake during exercise were high due to forced water intake and high thermal stress. As stated in the introduction, the ACSM guidelines for sodium intake prior to exercise were almost completely unsubstantiated. These results indicate that it may not be necessary to replace sodium losses during exercise if anticipated losses are ingested before exercise. Also, this finding supports the concept that if individuals are predisposed to overdrinking during exercise, additional sodium either in the diet or in hydration beverages may be warranted.

Last, although we demonstrated that beverage composition before exercise can affect both dipsogenic drive and kidney function resulting in improved body water status during exercise, we did not observe reductions in cardiovascular strain or temperature regulation. Also, performance decrements were not observed probably due to the short duration of exercise leading to insufficient dehydration. However, these data support ingesting high sodium meals prior to exercise in order to offset fluid and sodium imbalances and possibly performance decrements during exercise lasting longer than 2 hours where sweat losses are great.

### **Future Directions**

The research contained within this dissertation confirms the hypothesis that drinking behavior and water retention, can be altered not only by beverages ingested during and after, but also before exercise. However, this research has been, for the most part, applied. While this type of research allows us to make direct recommendations to people exercising in conditions where sweat losses are high, it does not allow us to infer the direct mechanism responsible for the effects. If the mechanism for this effect was known, interventions or

supplementation could be developed to optimize these results and provide overall better hydration of this population.

Commercial assays are available to test changes in kidney-regulating hormones; such as AVP, ALD, PRA, and ANGII. The inclusion of these measurements in the analyses would help to determine whether the effects are plasma or pressor. Also, research investigating what augments plasma osmolality independent of sodium ingestion would help elucidate whether the effects on fluid balance are truly due to changes in blood composition or whether the effects lay within the realm of oropharyngeal/gastrointestinal tract receptor stimulation. As mentioned in the review, safe, effective, osmotically active substances such as glycerol could be used to increase plasma osmolality without simultaneous sodium ingestion. Last, there is some evidence that exists for gastrointestinal tract hormones, such as uroguanylin, directly influencing kidney function.

Finally, this research could be followed up to determine the rates of gastric emptying and intestinal absorption after chicken noodle soup ingestion. It is possible that gastric emptying/intestinal absorption after soup ingestion are very quick, leading to a rapid reduction in mechanoreceptor stimulus and a disinhibition of thirst associated with normal fluid ingestion. Our second study provides some evidence of this due to extremely rapid changes in plasma osmolality, within 15 min, compared with salt water and plain water ingestion.